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THE APPLE MAGGOT[1]

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THE UNITED STATES DEPARTMENT OF AGRICULTURE IN COOPERATION WITH THE CONNECTICUT AGRICULTURAL EXPERIMENT STATION

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INTRODUCTION

Everyone living in the country, in New England and near-by States, is familiar with the disappointment experienced on biting into a "railroaded" or maggoty apple. Many such apples give no external warning that anything is wrong, although their interior may be a broken-down mass of rotten pulp. Such a condition is caused by the apple maggot (*Rhagoletis pomonella* Walsh), which in the region referred to is one of the major insect pests attacking the flesh of the apple.

Under the direction of Dr. A. L. Quaintance, a study of this important insect was undertaken in 1917 at the field station then established at Wallingford, Conn., by the Bureau of Entomology, in cooperation with the Connecticut Agricultural Experiment Station.[3] The results of studies of this insect and experiments with its control, which continued through 1922, are included in this bulletin.

[1] *Rhagoletis pomonella* Walsh; order Diptera, family Trypetidae.

[2] The writar was assistad in 1919 and 1920 by C. H. Aldan, in 1921 by H. M. Tiatz, and in 1922 by S. W. Bromley.

[3] Praliminary work on the insect was carriad on by E. H. Siegler, in charga of tha station in 1917, 1918, and the early part of 1919. During this period the writar acted as assistant; at its close ha was given charga of the work.

HISTORICAL

As early as 1865 the apple crop of New England was being seriously injured by the apple maggot. As an interesting coincidence, one of the first records of damage to fruit by this insect came from the point where were conducted the studies here described—Wallingford, Conn. "The Circular" of the Oneida Community, published at Wallingford, in its issue of November 12, 1866, made the following complaint (*42*):[4]

> Two months ago, we were congratulating ourselves on a fair crop of winter-apples. To all appearance, they were freer from worms than we had known them in this section for years. But, alas! our hopes are again blasted. Although the *apple-worm* (the larva of the codling-moth, *Carpocapsa pomonella*) is not so numerous as in some seasons, the *apple-maggot* seems to be as prolific as ever. Two weeks ago, we overhauled two hundred and fifty bushels of apples that we had gathered and placed in store for winter use; and of that number we threw out fifty bushels, most of which had been rendered worthless, except for cider or hogs, by one or the other of the above-named insects; and still the work of destruction goes on. The apple-worm, by this time, has ceased his work, or nearly so; but the depredations of the apple-maggot continue up to the present time, converting the pulp of the apple into a mere honeycomb, and rendering another overhauling soon indispensable.

In 1867 Walsh (*42*) published a description of the apple maggot, based on material from two sources: Flies which emerged from pupae, evidently from apples sent to him from New England and New York, and flies which he had reared from haws in Illinois. Thus was indicated from the beginning the relation between the possible original host fruit and the host to which the insect has very extensively adapted itself.

Since the time of the early reports from New England and New York of injury caused by this insect to apples, it has been found occupying a steadily increasing range. It has been mentioned with increasing frequency in entomological publications, and in agricultural and horticultural papers in the sections where it is present. The records of the spread of the insect, and its appearance in new localities as an apple pest, will not be given here, as they are discussed in detail elsewhere in this bulletin.

In 1890 Harvey (*17*) published from Maine the first extended account of the species, the biology of which had been known only imperfectly up to that time. The only practicable method of control then known was the destruction of the fallen fruit while the maggots were still in it, and until 1912 little further was added to the existing knowledge of the life history of the species or of other possible means of control.

Illingworth (*20*) in 1912 published the results of several years of investigations. In addition to giving much biological information, he reported very favorably on results obtained with sweetened arsenicals, a small quantity of which was sprinkled in each tree to be protected. Similar baits had been used very successfully in Italy against the olive fly by Berlese (*2*) and in South Africa against the Mediterranean fruit fly by Lounsbury (*23, p. 84*) and by Mally (*24*). In his early experiments Illingworth used a soluble arsenical, such as potassium arsenate; he found later that nearly as good results were given by arsenate of lead, which is but slightly soluble and acts more slowly. He also observed that where a considerable quantity of arsenical residue from codling-moth and other

[4] Reference is made by italic number in parentheses to "Literature cited," p. 47.

sprays was still present when the flies emerged the maggot infestation seemed to be less severe. He had no opportunity to test these sprays experimentally, but this observation led to the development later of control measures which have been found satisfactory in a number of localities. The sweetened bait used by him has been replaced by arsenate of lead, applied as for the codling moth. Illingworth was also the first to record the occasional emergence of flies in the fall from maggots which entered the ground earlier in the same season.

In 1914 O'Kane (*26*) published in an extended bulletin a complete account of the various phases of the life history of the species. He also presented a detailed record of control experiments, which had given negative results with poisoned bait and other spraying and which pointed to the destruction of the maggots in the fallen fruit as being still the most practicable method of control. Extensive experiments indicated the proper intervals at which the drops from different varieties should be removed and disposed of. O'Kane was one of the first to note the fact that a certain proportion of the insects remained in the ground over two winters, emerging the second season after entering the ground.

In 1916 Severin (*38*) reported satisfactory results in Maine from the use in small orchards of sweetened baits containing soluble arsenicals, but he reported failure with the same material when used on trees scattered through a residential section. His best results were obtained in an orchard which in July had also been sprayed with arsenate of lead and lime-sulphur for other pests.

In 1917 Brittain and Good (*3*) published the results of studies and experimental work carried on in Nova Scotia, where the apple maggot had been doing serious damage for several years. These writers were the first to make an unqualified recommendation of cover sprays of arsenate of lead during the emergence period of the flies. Their conclusions were confirmed by work carried on in Ontario by Caesar and Ross (*5, p. 4*), the results of which were published in 1919. The following year further confirmation was added by Herrick (*18*), in a report of experiments carried on in the Hudson River Valley.

COMMON NAME

Beginning with the very earliest records of this species, it has been known for the most part as the apple maggot. A second name, sometimes used, is "the railroad worm," referring to the characteristic tunnels made by the larvae in their movements through the flesh of the apple. The American Association of Economic Entomologists has officially adopted for the species (*Rhagoletis pomonella* Walsh) two common names, "apple maggot" and "blueberry maggot," because of its importance on these two unrelated crops. Except for incidental mention of other hosts, this bulletin is concerned with the species as an apple pest only, and it will be referred to throughout as the apple maggot.

SYNONYMY

There never has been serious confusion in the scientific nomenclature used for the apple maggot. When Walsh (*42*) first described the species as *pomonella* he placed it in the genus Trypeta. In 1873 Loew (*22, p. 265–268, 329*) placed the species in the "small genus" (subgenus) Rhagoletis, which eventually came to be considered of generic rank.

The form *zephyria* Snow has been generally considered to be identical with *pomonella*, but Curran (*9*) has recently shown it to be distinct. He has also shown (*10*) that the form occurring in snowberry is distinct from *pomonella*, and has described it as new under the name *symphoricarpi*. Curran's conclusions, if correct, clear up many of the puzzling circumstances in the host relationships and the distribution of this species.

DESCRIPTION [5]

THE EGG

Length 0.84 to 1.02 mm., average of 25 measurements 0.90 mm. Width 0.23 to 0.27 mm., average of 25 measurements 0.25 mm. Elliptical, semiopaque, creamy white, with both ends slightly yellow and more opaque. One end tuberculate and a little more of a brownish-yellow color than the other; the tuberculate end faintly reticulate. (Pl. 1, B, C, D.)

THE LARVA

When full-grown the larva (pl. 1, E) is usually 6.5 to 8 mm. in length, and 1.5 to 2 mm. in width at the widest point, although smaller larvae are frequently found leaving the fruit. It is usually cream-colored, the exact color depending on the contents of the alimentary tract, which may have a greenish to a brownish tinge. In addition to the head region, the body consists of 11 apparent segments. Only a small part of the head region is visible; within the head, and extending back beyond the first abdominal segment, is a chitinized framework supporting the two rasping mouth hooks (cephalopharyngeal skeleton); at the anterior end of the head are two pairs of minute papillae. The anterior end of the body is pointed, the body gradually widening to abdominal Segments III to V, which are of much the same width; Segments V to X are of equal width; the last Segment (XI) is slightly wider than the others. From the side view the last segment has on the upper half an oblique flattened surface, slightly swollen around the edge; on the upper edge is a pair of prominent tubercles, on each side a pair of smaller ones, and on the lower edge one large prominent tubercle; below each of these large tubercles is another, slightly smaller one. On the flattened surface just mentioned are two large, prominent, raised, posterior, spiracular plates, separated by a space equal to the length of one plate; each plate has three brownish transverse slits nearly in line with those of the other plate; the two upper slits are parallel and widely separated; the lower slit is closer to the second, but slightly diverging toward the outer end; on the upper and outer edge of each plate are several small spines, or hairs. Between thoracic segments 1 and 2, laterally, are the anterior spiracles, in the form of yellowish-brown, fan-shaped structures, each composed of about 20 to 28 minute, finger-like papillae, arranged prominently along the edge, and several on the outside of the spiracle. The head and first thoracic segment are often retracted into the body, causing the spiracles to point forward.

In the intersegmental regions are a number of rows of minute spines, becoming much less numerous toward the anterior end of the body. The anal opening is prominent and has a large rounded fold on each side.

THE PUPARIUM

Length 4.2 mm. to 5.0 mm., average of 25 measurements 4.5 mm.; width 1.8 to 2.3 mm., average of 25 measurements 2.1 mm. When first formed the puparium is of a cream-white color, which rapidly becomes a golden brown, increasingly darker with age. It is broadly oval, its anterior end somewhat narrowed dorso-ventrally, the posterior end rounded; the head and much of the first thoracic segment are retracted, and the anterior spiracle protrudes a little forward and outward, suggesting a pair of tiny ears; the center of the posterior segment is drawn in, the posterior spiracles are still apparent as in the larva, but slightly darker in color. (Pl. 1, F.)

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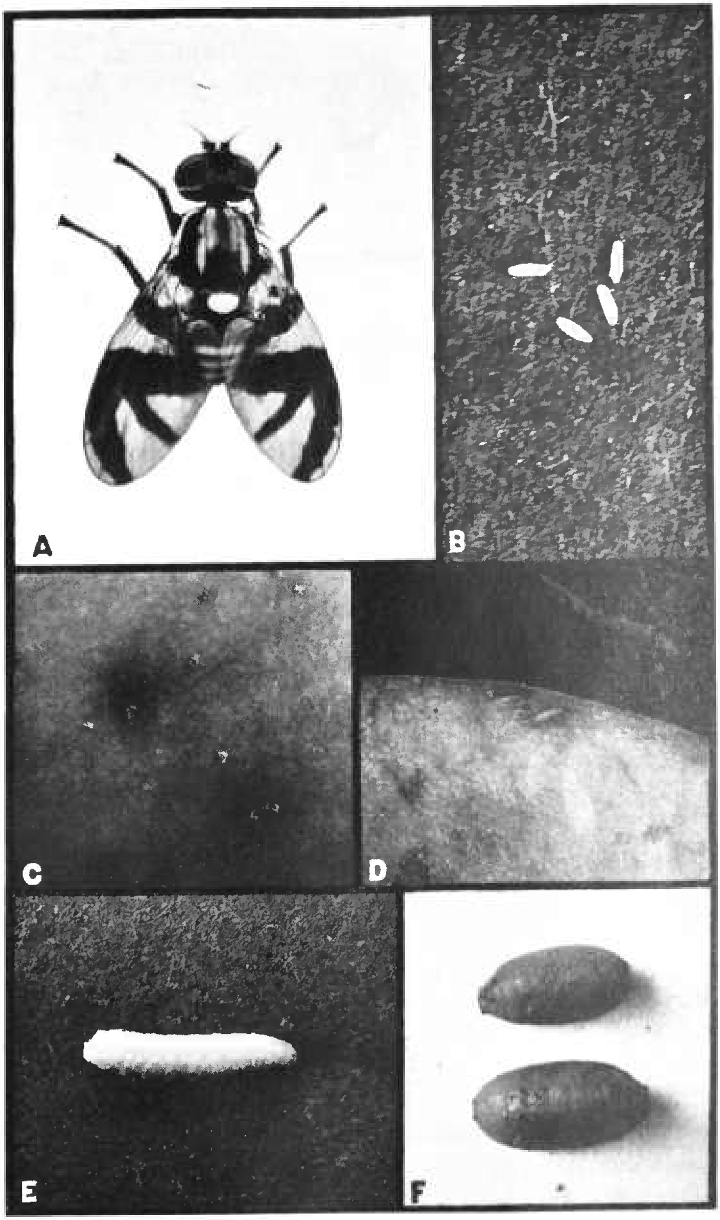
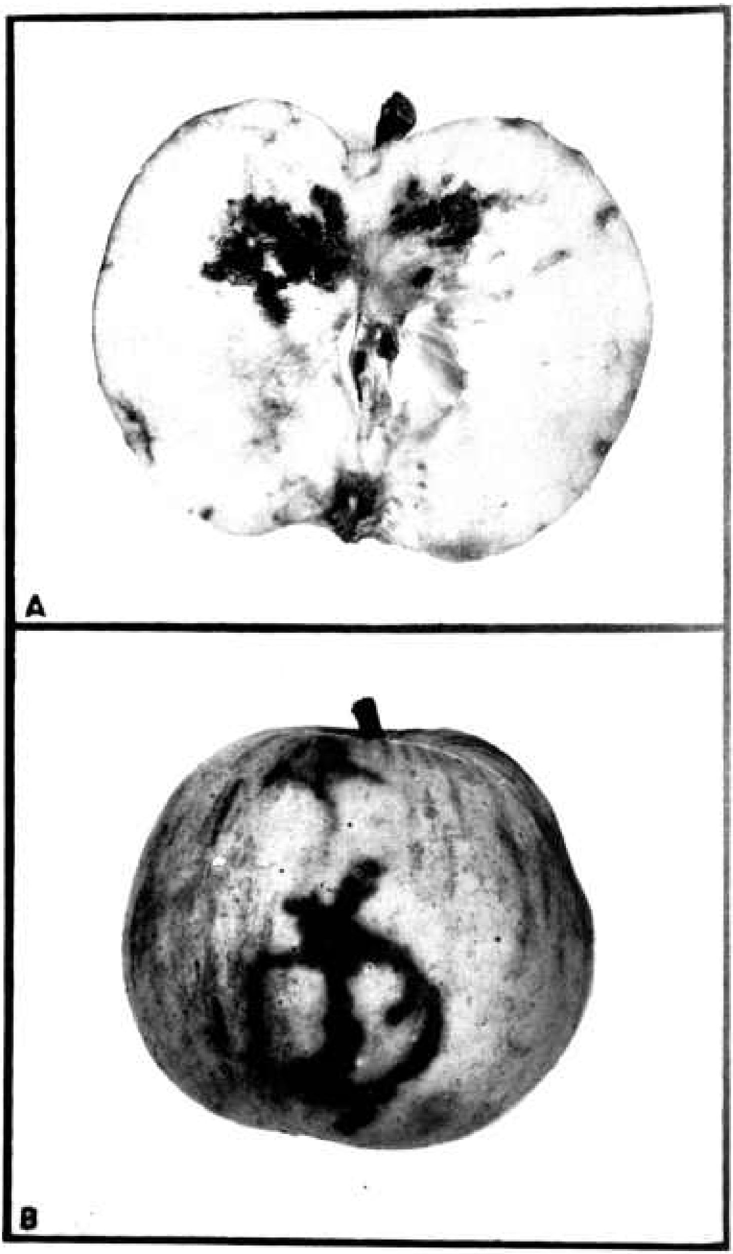
[5] The writer's thanks are here extended to C. T. Greene, of the Bureau of Entomology, for assistance in the preparation of these descriptions.



THE APPLE MAGGOT

A.—Female fly (× 8)
B.—Eggs removed from apple (× 8)
C.—Egg punctures in skin of apple (× 6)
D.—Eggs in normal position in apple (× 6)
E.—Larva, nearly full grown (× 5)
F.—Puparia (× 6)



WORK OF THE APPLE MAGGOT

A.—Section of a lightly infested apple
B.—Tunnels just underneath the skin of the apple
Approximately natural size

THE FLY

The following description of the adult (pl. 1, A) is quoted from Walsh (*43, p. 33*):

> *Head* rust-red; eyes and all the bristles black; front edge of the face and hind orbit of the eye, more or less tinged with white. *Thorax*, shining black; a humeral fillet, (vitta) and all but the extreme base of the scutel, white; on each side of the thorax, above, a gray fillet, opaque, with short, dense, gray pubescence. *Abdomen*, black, pubescent, with dusky hairs; the tip edge of the four basal segments white above, the white terminal edge of the first of these segments with short, white hairs; beneath, except the tip and a more or less distinct medial fillet, dull rust-red. Oviduct, short. *Legs*, pale rust-red; the four hind thighs, except the knees, black; the tips of the four hind paws (tarsi), and sometimes the front thighs, tinged with dusky. *Wings*, whitish-glassy, banded with dusky somewhat in the form of the letters I F—the I placed next the base of the wing, and its lower end uniting rather indistinctly with the lower end of the F; the base and the extreme tip of the wing being always glassy. The anterior end of the I commences on the transverse shoulder-vein and extends over the basal two-thirds of the second basal cell, and the whole of the third basal cell, beyond which it unites in a faint cloud with the foot of the F. The main leg of the F extends nearly in a transverse direction across the middle of the wing, straddling the middle transverse vein and the tip of the first longitudinal vein; from which last proceeds the anterior branch of the F, skirting, but not quite attaining the costa and the apex of the wing, and terminating on the tip of the fourth longitudinal vein. The posterior branch of the F commences opposite to the middle transverse vein, straddles the hind transverse vein, and terminates on the tip of the fifth longitudinal vein. Length of body, 0.15–0.20 inch; expanse of wings 0.30–0.43 inch.
>
> Described from six males bred from Eastern apples, July 15th–23d; two males and one female bred from Illinois haws July 23d–28th.

RELATED SPECIES

The apple maggot belongs to that group of insects known as "fruit-flies" from the fruit-infesting habits of the maggots. In the United States two species closely akin to the apple maggot (*Rhagoletis cingulata* Loew and *Rhagoletis fausta* O. S.) are often found attacking cherries; two other species (*Rhagoletis ribicola* Doane and *Epochra canadensis* Loew) infest currants and gooseberries.

In many tropical and subtropical countries serious damage is done to many kinds of fruits by the Mediterranean fruit-fly (*Ceratitis capitata* Wied.) In oriental tropical regions, and especially in Hawaii, the melon fly (*Bactrocera cucurbitae Coq.*) is a serious pest of melons and related plants, and of a few other fruits. In Italy and other southern European countries the olive fly (*Dacus oleae* Rossi) causes serious losses in the olive groves. In Mexico and Central America the Mexican orange maggot (*Anastrepha ludens* Loew) is a pest of considerable importance.

INJURY

Two forms of injury are caused by the apple maggot: (1) The flesh surrounding a puncture where eggs are deposited in immature fruit often fails to grow with the rest of the apple, and becomes a sunken, dimple-like spot in the surface. Ordinarily this injury is unimportant, but in extreme cases the fruit is seriously misshaped, suggesting certain forms of the work of the apple red bugs. (2) The second, and chief, form of injury is brought about by the larvae, which, as they feed and move through the apple, leave brown trails of broken-down tissue. (Pl. 2.) If several maggots are present in one apple the whole interior finally breaks down, and the apple becomes a worthless mass of rotten pulp, although it may still appear perfect externally. This injury is very characteristic, and there is little danger of confusing it with that caused by any other insect.

ECONOMIC IMPORTANCE

In the northeastern part of the United States and the neighboring region of Canada the apple maggot is undoubtedly a major pest of the apple, and there, in the case of the more susceptible varieties, it often does more damage than all other fruit-feeding insects combined. In such sections the planting of certain otherwise desirable varieties has been seriously curtailed because of this insect. Elsewhere the insect takes a position of lesser importance, and in many of the western and southern parts of its range it is reported only occasionally.

HOST FRUITS

ORIGINAL HOST

Since the apple maggot is not known to occur outside of the United States and Canada, and is evidently a native insect, it was doubtless present before the introduction from Europe of the cultivated apple. What fruit was originally the host of the apple maggot has often been a matter for speculation among entomologists. It seems very probable that the native host fruit was some species of Crataegus, or hawthorn.

CRATAEGUS

Some of the specimens from which the species was first described were reared from haws and others from apples. Since the insect was first described it has been recorded from haws from numerous localities widely scattered through the greater part of its known range. Some of these rearings have been from localities where the insect is virtually unknown as an apple pest. On the other hand, there have been many instances of failure, even after careful search, to find maggot infestation in haws in localities where apples were abundantly infested.

Wellhouse (*45*) reports rearing apple maggot flies from *Crataegus punctata*, *C. albicans*, *C. pruinosa*, *C. brainerdi*, and *C. macrosperma*, in New York State, and suggests that the species probably infests other large-fruited hawthorns also. He failed to find larvae in the small fruits of *C. neofluvialis* and *C. oxyacantha*.

CRAB APPLES

There are numerous records of the occurence of the apple maggot in crab apples. In most cases the fruit recorded is a variety of the Siberian or of a hybrid crab apple, and in no cases are records definitely referable to the native species of crab.

PEARS

Several instances are on record of the occurence of maggots of some species in pears, but in none of these cases do the adults seem to have been reared. A few maggots were found by the writer in Seckel pears at Wallingford, Conn., in Vermont Beauty pears at Amherst, Mass., and in an unknown variety of pear at Huntington, Mass. Unfortunately, in all of these cases attempts to rear the adults were unsuccessful. It seems likely that, if reared, the flies would have been found identical with *Rhagoletis pomonella.* Injury to pears seems to be not more than occasional, and probably occurs only when the pear trees are not far from heavily infested apples.

PLUMS

Herrick (*18, p. 91*) reports the rearing of apple-maggot flies from plums in the Hudson River Valley.

CHERRIES

The occasional references to the occurrence of the apple maggot in cherries are somewhat questionable. The species actually present is much more likely to have been one of the two closely related cherry fruit flies (*Rhagoletis cingulata* Loew and *R. fausta* O. S.).

HUCKLEBERRIES AND BLUEBERRIES

Flies apparently identical with *Rhagoletis pomonella,* although of smaller size than the average flies from apple, have been reared from *Vaccinium pennsylvanicum, V. canadense,* and *V. vacillans* in Washington County, Me. (*46*); also, although the smaller size is not specifically mentioned, from *V. corymbosum* in New Hampshire (*26, p. 18*) and from the huckleberry, *Gaylussacia baccata,* in Connecticut (*4*), New Jersey (*40*), and Maine (*48*). The writer has reared a long series of flies from huckleberries at Wallingford, Conn., but has had no satisfactory opportunity to make observations as to possible infestation in the various species of blueberry. In Washington County, Me., the maggots cause serious losses in the blueberry barrens.

SNOWBERRIES

Flies reared from maggots infesting the snowberry, *Symphoricarpos racemosus,* in British Columbia (*12*) and elsewhere in the Pacific Northwest, were for a long time considered identical with the apple maggot. As already mentioned, Curran has pointed out that the two forms are distinct.

CRANBERRIES

Phillips (*31, p. 136*) records the cranberry as a host of *Rhagoletis pomonella.*

APPLES

The change from the original host fruit to the apple seems to have taken place within the last hundred years or less. The fact that the insect escaped the notice of two of the pioneer economic entomologists, Peck and Harris, whose activities were carried on within the area which has evidently been infested for the longest period, would seem to indicate that the apple had not at that time been very generally accepted by the insect as a host fruit.

The earlier records of apple infestation, the spread of the area within which injury to the new host occurred, and the present distribution of the species as an apple pest, are discussed elsewhere.

IDENTITY OF FLIES FROM DIFFERENT HOSTS

Whether the flies which infest the different fruits are all of the same species is open to serious question. The occurrence of the species in fruit of hawthorn in localities in which the apple is free or virtually free from attack, the reverse condition in other localities, the presence of maggots in blueberries in certain restricted areas and in huckleberries in others, and the distinctly different habits of the blueberry flies from the flies in the apple orchard, all point to the possibility that there may be several distinct species, biological races, or incipient species, which at present can not be distinguished from one another. The fact that the two Pacific coast forms have already been shown to be distinct suggests that some day a similar condition may be found to exist with some of the eastern forms on different hosts.

Woods (*48, p. 260*) succeeded in obtaining puparia from larvae which when very small had been transferred from blueberry to chokeberry, but with this exception there seems to be no evidence that individuals from one host will adapt themselves to another. Owing to the difficulty invariably experienced in handling the flies in captivity, attempts to induce adults from one host to oviposit in another are almost certain to fail, and negative results under such circumstances have no significance.

VARIETAL SUSCEPTIBILITY

Marked differences in susceptibility to the attack of the apple maggot occur among the different varieties of apple. These differences are brought about chiefly by two factors—differences in the attractiveness of the fruit to the flies, and differences in the suitability of the fruit for the development of the maggots. For the most part the varieties of fruit most acceptable to the flies for oviposition are also well suited to larval development. Such seem to be for the most part the summer and fall varieties, especially those with sweet or subacid flesh, or with an aromatic flavor, or with both qualities.

The suitability of any given variety for the development of the larvae depends upon the ease with which the flesh may be broken down. Varieties which drop freely and early when infested (including most of the earlier maturing varieties) are very favorable to the development of the maggots. On the other hand, only a very small percentage of maggots may mature in very hard winter apples, whose flesh ripens and breaks down very slowly. If enough maggots are present, however, the hardest apple may be broken down, although a high percentage of the maggots present may perish during the process.

The degree of infestation in any given tree or group of trees depends not only on the primary factors already discussed but also on a long list of other factors, among which may be mentioned the presence or absence in the immediate vicinity of more susceptible varieties; the amount of fruit present in those varieties; the size of the crop and the degree of infestation in the previous year; the disposal of fruit in the preceding seasons; the character of the soil as affecting texture of fruit and time of ripening; cultural methods—sod or cultivation—which influence the time of ripening; the dropping of the fruit as a result of attacks of other insects; weather conditions which may hasten or delay the ripening of the fruit.

Frequent exceptions are found to the usual degree of susceptibility of almost all varieties. Often a tree or group of trees of a variety normally free from attack will develop a serious infestation, usually when close to a previously heavily infested tree of a more susceptible variety which may have failed to fruit, or which may have dropped its fruit before the flies were through ovipositing.

Table 1, stating the susceptibility of different varieties, has been compiled chiefly from observations by Harvey, O'Kane, Illingworth, Caesar and Ross, and Brittain and Good. In cases of a divergence of opinion all records are given. Records based on only a few trees have not been included, as these instances may have been unusual.

TABLE 1.—*Susceptibility of different varieties of apple to attack by the apple maggot* [a]

Variety	Flavor	Time of maturity	Degree of infestation: Severely	Moderately	Sparingly
Alexander	a	m	(*30*)	4, 5	1, 2
Arctic	sa	l			5
Bailey Sweet	vs	m		3	1, 2
Baldwin	sa	l		3	1, 2, 4, 5, 6
Baxter	ma	l			5
Ben Davis	sa	l		5	3, 4, 6
Benoni	sa	e	1, 2, 1	3	
Blenheim	sa	l			4, 5
Blue Pearmain	sa	l			3
Bullock	sa	m			1, 2
Canada Baldwin	sa	vl			1, 2
Catshead	sa	m			1, 2
Chenango	sa	ma	1	6	2, 4
Colvert	bsa	m		5	1, 2
Cooper Market	sa	vl		5	
Cox Orange	bsa	m	(*13*)		4
Crab, Hyslop	sa	m		5	
Crab, Transcendent	sa	ma	5, 6		
Crab, Whitney	sa	ml		5	
Cranberry Pippin	bsa	l		5	
Danvers	s	l		3	1, 2
Dayton	sa	ml			1, 2
Derby	sa	l			1, 2
Dutch Codlin	sa	me			4
Dyer	msa	m			2
Early Harvest	sa	e	1, 2, 3, 5, 6		
Esopus Spitzenburg	sa	ml	1 (*29*)	3	
Fallawater	msa	ml			3, 4
Fall Harvey	sa	m	3		
Fall Jenneting	bsa	m	1, 2, 4	5	
Fall Pippin	sa	m	2	6	1
Fameuse	sa	m	2, 3, 5 (*30*)		1
Foundling	sa	me		3	
Franklin Sweet	s	l	1, 2		
Gano	msa	l			3
Garden Royal	sa	me	1, 2, 3		
Garden Sweet	s	m	3		
Gideon	a	e		5	
Golden Ball	sa	l			1, 2
Golden Russet	sa	l		3	1, 4, 5
Golden Sweet	s	me			1, 2
Gravenstein	sa	m	1, 2	3, 4, 6	
Grimes Golden	sa	ml		3, 4	1, 2
Haas	sa	m		5	
Henderson	s	ma	2		
Hightop Sweet	vs	ve	1, 2		
Holland	sa	me			5
Hubbardston	sa	ml		3	1
Hurlbut	sa	m	1, 2	3, 6	5
Irish Peach	sa	me			1, 2
Jersey Sweet	s	me	2		
Jewett Red	msa	ml	1, 2, 3		
King of Pippins	a	me	2		

Variety	Flavor	Time of maturity	Degree of infestation: Severely	Moderately	Sparingly
King Sweet	s	m	1		
Lady Sweet	s	vl			1, 2
Maiden Blush	sa	m		3, 5	1, 2, 4
Mann	sa	vl			3, 5
McIntosh	sa	ml		3	5, 6
Mexico	sa	m			1, 2
Minister	a	ml	3		
Mother	sa	ml	1, 2		
Munson	s	m	1, 3		2
New York Sweet	s	e	1, 2		
Nonpareil	msa	l			4
Northern Spy	sa	l	1, 2, 3, 5, 6		4
Oldenburg	sa	me	2	3, 4	1, 5, 6
Peach of Montreal	sa	m		3	
Pewaukee	bsa	l			4, 5
Phoenix	sa	l		5	
Porter	sa	m	1, 2, 3, 6		
Pound Sweet	s	l	2		1
Primate	sa	me	2		1
Pumpkin Sweet	vs	m	1, 2, 6	3, 4	
Ramsdell	s	ml			1, 2
Red Astrachan	a	me	1, 2	3, 6	4, 5
Red Canada	bsa	vl		3	
Red Detroit	sa	ml			2
Red Russet	sa	l			4
Rhode Island Greening	a	ml		3, 5, 6	1, 2, 4
Ribston	a	vl			1, 2, 4
Rolfe	sa	ml			1, 2, 3
Roxbury Russet	a	vl		3	
Russell	sa	e	1, 2		
St. Lawrence	sa	m		3, 5	
Smokehouse	sa	ml	6		
Somerset	sa	m			1, 2
Sops of Wine	sa	me	1, 2	3	
Stark	ma	vl			4, 5
Swaar	sa	ml			2
Sweet Bough	s	e	1, 2, 3, 4, 5, 6		
Sweet Russet	s	ml			2
Tetofski	a	me	1, 2, 6		
Tolman Sweet	s	vl	1, 2, 3, 5	4	
Tompkins King	sa	l		3, 6	1, 2, 4, 5
Twenty Ounce	sa	ml	2 (*30*)	3, 6	
Vandevere	sa	ml			4
Wagener	sa	ml	2	5	3, 4, 6
Wealthy	sa	ml	2, 5, 6 (*30*)	3, 4	
Westfield	sa	ml		3	2
Williams	sa	me		3, 6	2
Winter Paradise	s	l	1, 2		
Wolf River	sa	ml			5, 6
Yellow Bellflower	sa	ml		3, 4, 5	
Yellow Transparent	sa	me		3, 6	4, 5

[a] Names of varieties have been corrected to agree with those in Standardized Plant Names (*27*). Abbreviations under the heading "Flavor" are those used in Nomenclature of the Apple, by Ragan (*33*), as follows: a, acid; b, brisk; m, mild; s, sweet; sa, subacid; v, very. Similarly, the abbreviations denoting the season are e, early; l, late; m, medium; ml, medium to late; v, very. As the different varieties are not uniformly susceptible in all sections and under all conditions, the authority for each statement is given. The numbers under the different susceptibility columns refer to the following authorities: 1, Harvey, Me., 1889; 2, Illingworth, N. Y., 1912; 3, O'Kane, N. H., 1914; 4, Brittain and Good, Nova Scotia, 1917; 5, Caesar and Ross, Ontario, 1919; 6, author's observations, Connecticut, 1917–1922; italic numbers in parentheses refer to "Literature cited."

DISTRIBUTION

The distribution of the apple maggot coincides approximately with the so-called Transition Life Zone from the Dakotas eastward, including the southern extension of this zone along the Allegheny Mountains. The insect is also present in limited numbers in the Middle West in some parts of the Upper Austral Zone, but in these sections has never become a serious pest. Since Curran (*9*) has pointed out that two forms found on the Pacific coast are distinct from the species *pomonella*, and inasmuch as in that section the larvae are never found in apples, it seems very likely that records from Alberta, British Columbia, Oregon, and California refer to either *zephyria* Snow or *symphoricarpi* Curran. These records have therefore not been considered in preparing the accompanying map (fig. 1), which shows the approximate distribution of the apple maggot, according to information gained from correspondence, bureau records, and experiment

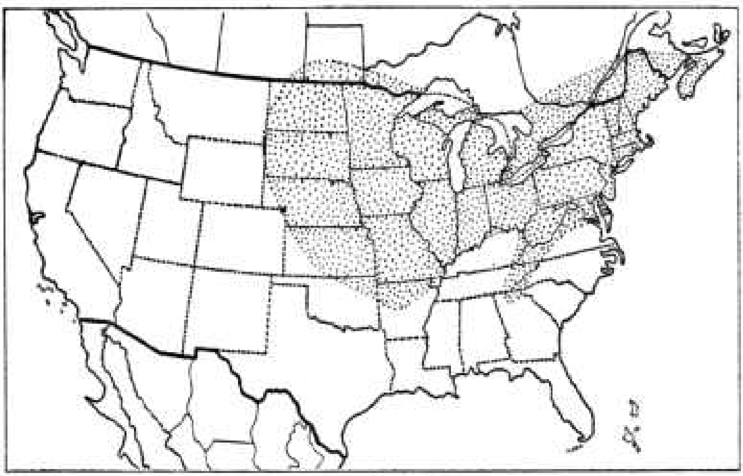


FIG. 1.—Probable approximate distribution of the apple maggot

station publications. This map is of necessity very general, and is doubtless erroneous in some details.

A more detailed discussion of the distribution of the insect and its status in different sections follows:

Nova Scotia. The apple maggot was first reported officially in 1914 (*25*), but had evidently been present for a number of years. It is serious in regions adjacent to the Bay of Fundy.

New Brunswick. No records are available, but the insect is very possibly present in the region lying between Nova Scotia and Maine.

New England. The pest has been present since about the middle of the nineteenth century, and is still serious.

Quebec. Serious injury began to be reported in 1904 (*14*). The insect is present in many localities in the southern part of this Province.

Ontario. The apple maggot has been present in southeastern Ontario, at least in haws, since 1887, and in cultivated fruit since 1896. It is now a serious pest.

New York. This insect has been a pest of first importance since it began to attack the apple. It is still important in many parts of the State, especially, according to Herrick (*18, p. 90*), in the Hudson Valley, along Lake Champlain, and at the eastern end of Lake Ontario.

Pennsylvania. Since 1908 the apple maggot has been reported at intervals from scattered localities, especially in the northeastern and central parts of the State.

New Jersey. The insect has been present since 1889, but seems to do little damage. It is more abundant at higher elevations.

Delaware. No records of occurrence.

Maryland. E. N. Cory writes that the insect is present in Garrett County, at the extreme western part of the State, at an elevation of 2,600 feet. Fred E. Brooks has captured flies of this species near thorn-apple trees at Oakland, in the same county. The species is apparently restricted to the mountainous regions of the State.

District of Columbia. Flies have been reared once from haws (*7, p. 196*).

Virginia.[6] Professor Schoene writes that there are apparently no records of the species in Virginia. It may be present at the higher altitudes, as it has been found in adjacent counties in West Virginia.

West Virginia.[6] Mr. Brooks has reared the flies from hawthorn fruits collected in Pocahontas County, and has also observed infested haws in Tucker County.

North Carolina. Howard (*19*) records finding the insect in an apple received from Waynesville.

Tennessee. No definite information is available but the apple maggot will probably be found in the mountainous sections of the State.

Kentucky. Professor Garman writes that there is no record of the pest in Kentucky. It may occur in the mountains.

Ohio. The insect has been occasionally reported since 1889 from scattered localities, chiefly from the northwestern part of the State. It is seldom serious in Ohio.

Indiana. O'Kane (*26, p. 23*) quotes Professor Troop as saying that the maggot is to some extent present in Indiana. The writer was unable to find infested fruit in the orchards of southern Indiana in the summer of 1923. He has, however, found what appears to be this insect in haws across the Wabash River from Vincennes.

Michigan. The apple maggot has been present since 1884 (*8*), occasionally doing serious damage.

Wisconsin. The species was reported in haws in 1883 by Cook (*8*). Fracker[7] states that the apple maggot, normally rare in Wisconsin, was in 1921 a serious factor in some localities in the central portion of the State.

Minnesota. The apple maggot was first recorded by Washburn in 1903 (*44*). In 1922 it was reported to be giving serious trouble (*36*).

Iowa. Reported by Osborn (*28, p. 62*) in 1892 as having been common in 1890; it has received occasional mention since, but has seldom been of importance.

Illinois. The original description of the apple maggot was based partly on material reared from Illinois haws; Flint wrote in 1924 that no further reports bad been made, at least none which had been confirmed by actual specimens or by the observations of anyone connected with his office. In the fall of 1924, on the banks of the Wabash, opposite Vincennes, the writer made the collection of infested haws referred to above.

Missouri. No definite records have been available.

Arkansas. Dwight Isely, formerly of the Bureau of Entomology, informs the writer that he has reared a single adult apple maggot fly in the northwestern part of the State.

Kansas. Dean and Peairs (*11*) report that the apple maggot is occasionally observed in Kansas orchards but not in great numbers.

Colorado. A single apple-maggot fly was captured by Gillette in 1896. In 1914 O'Kane (*26. p. 22*) quotes him as saying that he has never seen the work of the species, and that the individual which he captured might have come from infested fruit shipped in from the East.

Nebraska. No record of occurrence.

South Dakota. Reported by Severin in 1922 (*37, p. 24*) as being widespread in orchards, but serious in few of them. J. M. Aldrich has taken flies at Brookings, S. Dak.

North Dakota. Recorded by Phillips (*31, p. 136*).

Manitoba. Recorded from Aweme, by Gibson (*15, p. 157*) in 1916.

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[6] In 1927 serious outbreaks of the apple maggot occurred at a number of points in Virginia and West Virginia, this being the first record of commercial damage to the apple in these fruit sections.

[7] FRACKER, S. B. APPLE MAGGOT. U. S. Dept. Agr., Bur. Ent. Insect Pest Survey Bul. 1: 241. 1921. Mimeographed.]

DISSEMINATION

Dissemination of the apple maggot over short distances may be accomplished by flight, but it is doubtful if a very rapid spread of the insect is brought about by this means.

In the larval stage the maggots in the fruit may be artificially transported for great distances, and without doubt a few of those maturing in such fruit find satisfactory places for pupation and emerge later as flies. If suitable fruit is then available for oviposition, and conditions are otherwise favorable, a new infestation may result. The spread of the species, however, at least as a serious pest, seems to have been confined approximately to what is known as the Transition Life Zone, which includes the region along the Canadian border, the New England States, and some more southern areas having a higher elevation. It seems inconceivable that it has not been repeatedly introduced in infested fruit into the more southern regions, and the mere fact that it is not yet considered a pest there seems evidence that the species does not readily adapt itself to conditions prevailing south of the Transition Zone.

It would be hazardous to make definite prophecy regarding the future range of the species as a serious pest, but present evidence is against the probability that it will become serious south of its present range. On the other hand, there seems to be no factor recognized at present which would prevent its becoming an important injurious insect in the fruit sections of the Pacific Northwest.

SEASONAL HISTORY AND HABITS

BRIEF OUTLINE

Before proceeding with a detailed discussion of this insect's seasonal history, it may be well to outline briefly its usual life cycle.

Winter is passed in the ground in the pupal condition. In the summer the adult flies leave the ground and insert their eggs into the apples, just underneath the skin. The maggots hatching from these eggs tunnel through the apple, breaking down the pulp, and leaving characteristic brown trails behind them. When mature, the maggots leave the fruit, which ordinarily has meanwhile fallen to the ground, and enter the soil. There they transform into the resting, or pupa, stage. The majority of the pupae remain in this condition until the following summer, except that in southern parts of the infested area a few flies may leave the ground in the season in which the pupation took place. In all localities a certain proportion of them do not appear until the second summer.

DIFFICULTIES IN LIFE-HISTORY STUDIES

In the study of many of the phases of the life history of the apple maggot serious difficulties have been encountered. The flies do not take readily to captivity, and only rarely can they be induced to lay eggs in insectary cages. This difficulty has been reported by all investigators who have worked with the insect. The exasperating behavior of the captive flies may be summed up by the following words, quoted from O'Kane (*26, p. 45*):

> In fact, the larger the cage built, and the more nearly the conditions appeared to approach normal, the more apt the flies were to refuse to live out their existence to full period and in rational manner.

For this reason information concerning the preoviposition period, and concerning some other details of life history which can be best secured with insects in captivity and under close observation, is rather

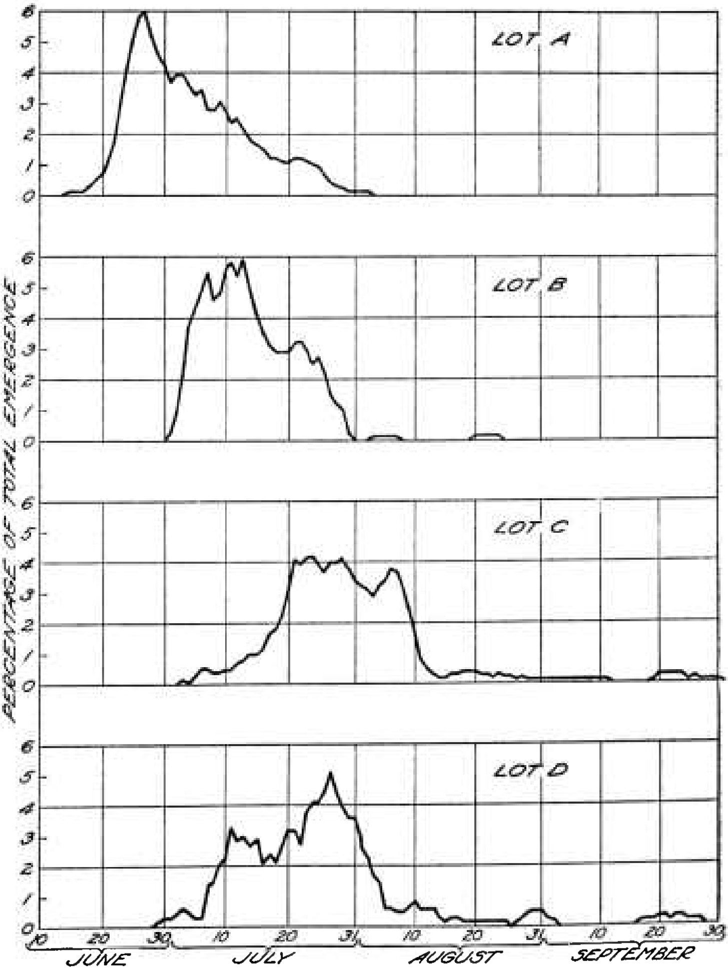

FIG. 2.—Daily emergence of flies at Wallingford, Conn., in 1918, from material put into soil cages in the fall of 1917. Lot A, 882 flies in 2 cages, in sunlight, of material from summer fruit, with larvae and puparia previously emerging from summer fruit; lot B, 185 flies in 1 cage, in partial shade, o material from summer fruit; lot C, 292 flies in 2 cages, in partial shade, of material from fall fruit; lot D, 133 flies in 2 cages, in sunlight, of material from fall fruit

meager. However, reasonably accurate information concerning many of the more difficult points has been secured by field observation and other means.

TIME OF APPEARANCE OF THE FLIES

Throughout the progress of the studies the emergences of the flies from the ground were observed daily, care being taken in every case to make the observations cover the entire season of emergence. For this purpose wooden soil cages, 18 to 20 inches square, were constructed in the insectary yard. These extended several inches into the ground and from 4 to 8 inches above ground, and were fitted with hinged screen tops. In a few of the cages used in the first two years maggots and newly formed puparia were placed; in the remainder of the cages used in these two seasons, and in all cages used in subsequent years, were placed heavily infested apples. This permitted the maggots when mature to enter the ground normally. The flies were removed from the cages daily during the period when emergence was taking place.

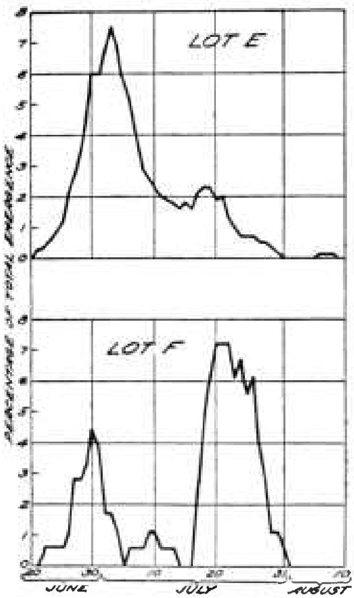

FIG. 3.—Daily emergence of flies at Wallingford, Conn., in 1919, from material put into soil cages in the fall of 1918. Lot E, 466 flies in 6 cages of material from summer fruit, with larvae and puparia previously emerging from summer fruit; lot F, 36 flies in 6 cages of material from fall fruit, with larvae and puparia previously emerging from fall fruit. All cages were in partial shade

Figures 2 to 6 show the emergence of the flies as recorded during the period 1918 to 1922. The curves have been partially smoothed by the sliding-average method, each day's emergence being averaged with those of the two preceding and the two following days. In order that the curves may be comparable, the figures have been reduced to a common basis—the percentage of the total season's emergence, for the group concerned, which occurred each day. The total number of flies on which each curve is based is noted in the legend. The cages have been grouped according to the source of material—summer, fall, or winter fruit—and according to the location of the cages, whether in sun or partial shade. As will be shown later, these factors have an influence on the time when the flies emerge.

Two sets of emergence records originally made have not been included in these curves, since the number of flies emerging was insufficient for needed accuracy.

DISCUSSION OF EMERGENCE RECORDS

EMERGENCE FROM EARLY FRUIT AS COMPARED WITH THAT FROM LATER FRUIT

The emergence data, as presented in graphic form, indicate that the time of maturity of the fruit in which the maggots develop has a definite influence on the time when the flies emerge in the following season. In all cases the curves for the emergence of flies which developed as larvae in summer fruit rise at an earlier date than do those for the emergence from material which developed in fall or winter fruit, although at the beginning of the season and toward its close there are occasional irregularities, owing to the emergence of a very few individuals unusually early or unusually late.

The number of flies emerging from winter-fruit material was too small to establish the relation between emergence from such material and that from earlier fruit. The extremely high mortality of maggots developing in winter fruit renders it impracticable to obtain large numbers of flies from this source.

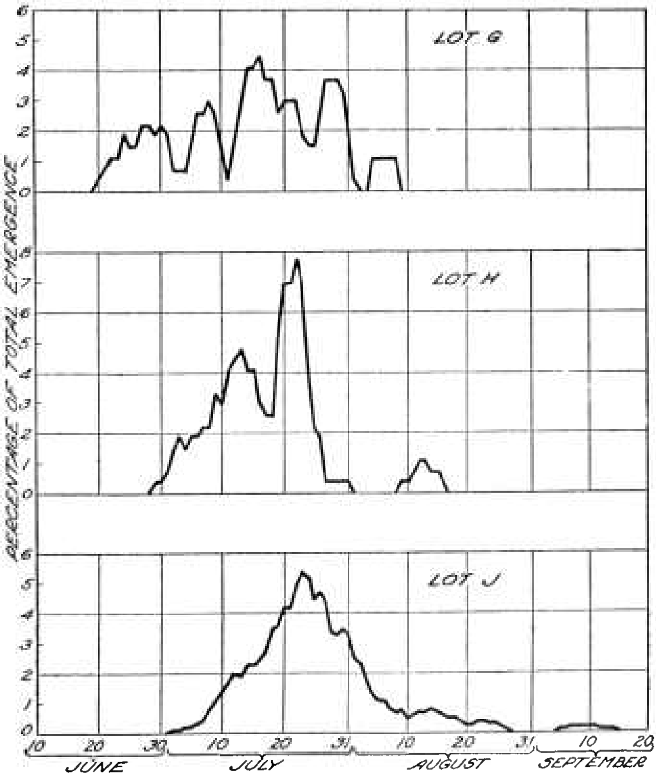

FIG. 4.—Daily emergence of flies at Wallingford, Conn., in 1920, from material put into soil cages in the fall of 1919. Lot G, 54 flies in 1 cage, in sunlight, of material from summer fruit; lot H, 54 flies in 1 cage, in partial shade, of material from summer fruit; lot J, 264 flies in 7 cages, in partial shade, of material from fall fruit. (Lot I, of 20 flies, and lot K, of 22 flies, omitted)

From a practical standpoint, this difference in time of emergence indicates that spraying for the control of the pest in orchards of late varieties may be safely deferred for at least a week after it is necessary to protect early fruit. It also indicates that emergence in orchards which include both summer and fall varieties will continue over a longer period than in orchards of summer fruit only, or of fall and later fruit only.

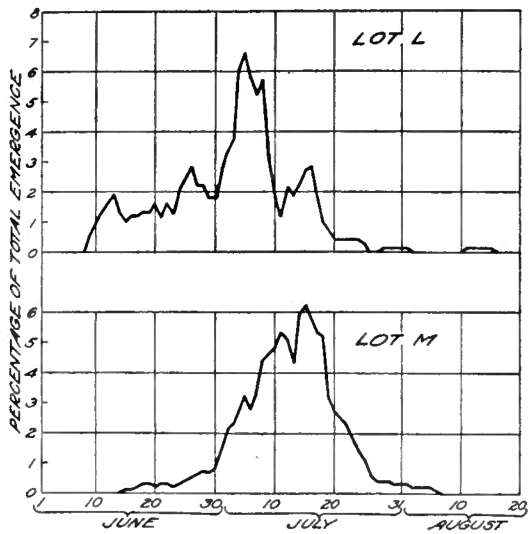

FIG. 5.—Daily emergence of flies at Wallingford, Conn., in 1921, from material put into soil cages in the fall of 1920. Lot L, 134 flies in 4 cages of material from summer fruit; lot M, 917 flies in 17 cages of material from fall fruit. All cages were in partial shade

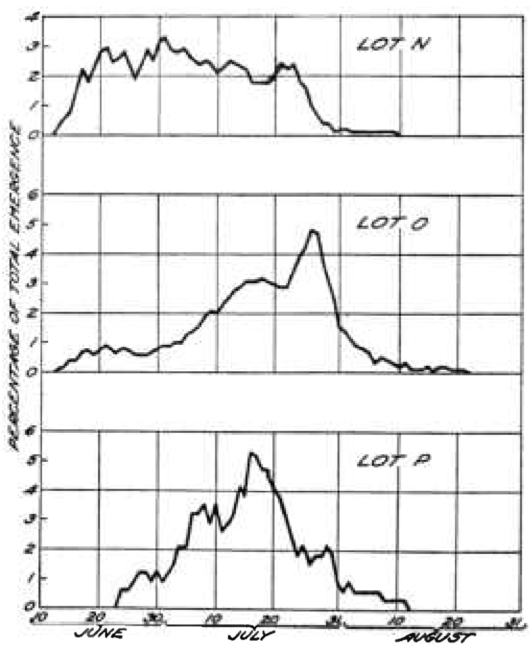

FIG. 6.—Daily emergence of flies at Wallingford, Conn., in 1922, from material put into soil cages in the fall of 1921. Lot N, 917 flies in 3 cages of material from summer fruit; lot O, 1,663 flies in 13 cages of material from fall fruit; lot P, 68 flies in 4 cages of material from winter fruit. All cages were in partial shade

EMERGENCE FROM LOCATIONS IN THE SUN VERSUS LOCATIONS IN SHADE

Generally speaking, the flies emerged earlier from cages in the sun than they did from similar material in cages in the shade, although there have been some exceptions to this rule. Orchard conditions are for the most part those of partial shade.

EFFECT OF RAIN

Although some writers have pointed out an apparent increase in the emergence of flies immediately after rains, the data obtained at Wallingford fail to demonstrate such a relation. In many cases the greatest number of flies appearing at any time during the summer left the ground during a dry period. For instance, the heaviest emergence of the season of 1918 occurred June 25 to 28, although no rain had fallen after June 22. Similarly, in 1919, the maximum emergence took place in the interval from July 1 to July 5, although no rain had fallen after June 26.

It is probably true that flies do not emerge freely from a soil which has become baked and dry; in such a case a rain may serve to facilitate emergence. In the records secured at Wallingford there are a few instances of increased emergence following a rain, but there are more instances in which rainfall has failed to increase the number of flies appearing, even when it occurred early in the emergence period and many flies emerged afterwards.

INFLUENCE OF TEMPERATURE

A continuous thermograph record of air temperatures was kept during the course of these studies. No significant relation was observed between temperatures and the rate of emergence of the flies. In some cases the maximum emergence took place with average temperatures between 59° and 63° F.; in other cases the most flies left the ground when average temperatures ranged from 72° to 82°. Emergence of second-brood flies, to be discussed in detail later, took place in greatest numbers when average temperatures ranged a little above 50°, and occasional flies appeared when the temperature was only a few degrees above the freezing point.

Because of this evident lack of correlation between temperature and emergence, detailed weather records have been omitted.

EMERGENCE BY NIGHT AND BY DAY

Observations made morning and evening indicated that the majority of the flies emerged during the hours of daylight.

PROPORTION OF SEXES

A summary of the data concerning the proportions of the respective sexes is given in Table 2. From this table it appears that, disregarding the few flies which escaped before their sex could be noted, 58.3 per cent of the flies which emerged during the period 1918 to 1922, inclusive, while these studies were carried on at Wallingford, were females. Caesar and Ross (*5, p. 17*) found in their studies that the proportion of females was 67 per cent, 421 males and 840 females emerging from rearing cages in three seasons, while Brittain and Good (*3, p. 19*) found in Nova Scotia that the percentage of females ranged from 57.8 to 62.

TABLE 2.—*Proportion of sexes of flies as shown by the emergence records of 1918 to 1922, inclusive, at Wallingford, Conn.*

Year	Brood [a]	Males	Females	Total
1918	Main brood	613	810	1,423
	Second brood	177	267	444
1919	2-year cycle	79	92	171
	Main brood	208	292	500
	Second brood	0	1	1
1920	2-year cycle	2	16	18
	Main brood	186	224	410
	Second brood	9	15	24
1921	2-year cycle	16	24	40
	Main brood	417	621	1,038
	Second brood	53	53	106
1922	2-year cycle	118	152	270
	Main brood	782	1,145	1,927
	Second brood	1	5	6
	Total	2,661	3,717	6,378

[a] The term "brood" is here used for convenience in referring to the different groups of flies which may emerge from any given lot of material. The term "main brood" refers to those flies which emerge in midsummer from material which entered the ground in the preceding season; these follow the more usual life cycle and ordinarily constitute the greater part of the flies which appear during the season. "Second brood" refers to the group of flies which appear in the fall from material which entered the ground in the same season. Two-year-cycle flies are those which have remained in the ground as pupae 2 winters.

Flies of both sexes appear in the cages at all times in the season, but the proportion of females is greatest in the early part of it. The males appear in relatively greater numbers near the close of the emergence period.

In the field it appears that the male flies greatly outnumber the females. In collecting flies for study it has been a common experience to capture several males for each female caught. The authors quoted above (*3, 5*) have observed the same condition. Evidently the females spend less of their time in situations where they may be easily observed and captured.

HABITS OF THE FLIES

When the fly first leaves the ground its body is rather soft, the wings have not fully expanded, and the color is a pale, ashy gray, with the dark and light areas not so distinct as they later become. On exposure to the air the wings gradually expand and their dark areas become darker and more distinct; the body hardens, and its dark and light markings become clear-cut. The entire process, from the time the fly leaves the ground until it is ready for flight and fully colored, lasts from two to four or more hours.

Although the flies often give one the impression of sluggishness, they are really active and quick of motion. Their movements over the fruit and leaf are apparently rather deliberate, but with fairly frequent sudden starts and spasmodic movements. The wings are often quickly raised and lowered with a very characteristic motion. Short distances through the air, as from twig to apple, or from apple to leaf, are covered with a hop or quick dart. When greater distances are to be covered, the flies dart away with a swiftness surprising in an insect apparently so sluggish. In the cooler parts of the day the flies can with little difficulty be caught in an inverted vial, and are easy to handle in insectary cages; but when temperatures are higher their capture is much less easy, and they have a decided tendency to dart away through any opening offered, even for only a brief moment.

On cool days the flies are to be found in the sunny parts of the tree; on hot days they spend more of their time in the partially shaded locations. No part of the tree is entirely avoided, however, as is proven by the severely infested condition of apples from all parts of trees in orchards where the flies are abundant.

Mating evidently does not occur until a number of days after the flies have emerged. In cages, copulation was not observed until the flies were 10 to 20 days old, although, as already noted, observations made with captive flies of this species have little significance. In the field, mating is not usually observed until a week or more after emergence is well under way.

FEEDING

The feeding habits of the flies have been frequently observed and recorded. Briefly stated, the apple-maggot fly feeds, much as the house fly does, on both liquid and solid substances. Liquid substances, such as drops of dew or rain water, aphis honeydew, and the like, are sucked up through the proboscis. Solid materials seem to be brought into solution or fine suspension by a drop of liquid forced out from the mouth parts and later sucked in again. The flies seem to be almost continually tasting of the surface materials present wherever they may chance to be.

Observations seem to indicate that previous to oviposition the flies spend less of their time on the fruit than after oviposition has begun.

DISPERSION

The dispersion habits of the flies, vitally important from the standpoint of control, have long been a matter of speculation, and very divergent views have been expressed about them. Conclusive evidence has been difficult to obtain. Small numbers of marked fles have been liberated in numerous experiments, including several conducted by the writer, but no information has resulted, owing to the refusal of the flies to enter traps and the consequent inability to recapture them.

The opinions held in this matter by different observers have been of necessity based on circumstantial evidence and on general observation. These opinions have varied from the belief that the flies tend distinctly to localization to the opposite view that they move freely and continually from tree to tree within a given orchard, if not from one orchard to another. More recent workers have inclined to the latter view.

The three years of experiments conducted at Milford, Conn., which are described in detail elsewhere in this bulletin, have thrown some additional indirect light on the problem. In these experiments, when the treated portions of the orchard were closely adjacent to the untreated portions, the control obtained was approximately 50 per cent. When only an isolated portion of the orchard was left unsprayed the control obtained was 80 per cent in one season and 95 per cent or more in another. As the object of this treatment was to kill the adults before oviposition, the more nearly uniform infestation in the sprayed and unsprayed portions when these were near together seems to indicate that the infestation tended to be equalized by continual movement of the flies from tree to tree. Many flies were doubtless killed in the poisoned plats, but the movements of healthy flies from the check plats tended to neutralize this benefit.

These observations cause the writer to concur in the opinion expressed by Caesar and Ross (*5, p. 31*), who say, "It is a dangerous assumption to make that the flies do not move around from tree to tree in the orchard. The results obtained by spraying show that both this insect and its close relatives, the cherry fruit flies, do move about much more than was previously supposed."

PREOVIPOSITION PERIOD

When the female fly emerges from the ground, her ovaries are in a very undeveloped condition, and some time must elapse before her eggs are ready for deposition. Dissections of large numbers of flies at Wallingford have shown that nearly all of the ovaries in the newly emerged flies are in the very immature condition figured by Illingworth (*20, fig. 34*) for such flies. A very few flies have been noted shortly after emergence with ovaries slightly more advanced than the earliest stage noted by that worker.

The length of the period needed for the maturing of the eggs has never been satisfactorily determined, owing to the failure of the flies to behave normally in confinement, and to oviposit to any extent under insectary conditions. Illingworth (*20, p. 144*) found the period with captive second-brood flies to be from 20 to 24 days, from which he estimated that the corresponding period for first-brood flies would be about 2 weeks. O'Kane (*26, p. 45*) found periods of 4, 6, and 8, or more days, but very few eggs were laid in an extensive series of experiments. Efforts by other investigators to determine the length of this period have yielded results falling between these extremes, or have failed entirely.

Experiments at Wallingford have unfortunately added little information to that already obtained. Large numbers of flies have been used and numerous types of cage were tried, but egg laying rarely occurred. Of 13 flies which laid eggs in captivity in July, 1918, 3 had a preoviposition period of 14 days, 1 of 16 days, 2 of 17 days, 1 of 18 days, 1 of 21 days, 2 of 27 days, 2 of 28 days, and 1 of 32 days. Of 4 flies which laid eggs in July and August, 1920, 1 had a preoviposition period of 13 days, 2 of 14 days, and 1 of 24 days.

Dissections of numerous flies which have been maintained in captivity throughout their lives revealed the fact that in most cases the development of the eggs was proceeding very slowly or not at all. This abnormal behavior of the flies in captivity leads one to doubt the value of preoviposition records obtained under such conditions.

During several seasons frequent observations were made in certain orchards, and an attempt was made to note the time of the earliest emergence of the flies, and later the time when the first eggs were laid. It was impossible to make observations every day, especially on stormy days, on which the flies are inactive. It was of course impossible to be sure that the first flies seen had just emerged, and had been the first to emerge. The intervals between the emergence of the first fly and the first observed oviposition were in 1920 not less than 7 and not more than 10 days; in 1921, not less than 4 days and not more than 8; in 1922, not less than 4 days and not more than 10.

The best that can be done on the basis of the unsatisfactory and conflicting evidence available is to hazard the guess that under field conditions in early summer the preoviposition period may be at least a week.

OVIPOSITION

Many workers have observed the process of oviposition. The fly walks around on the surface of the apple, making frequent side steps and quick turns, the wings being often flicked up and down in the characteristic manner already mentioned. After some search, a suitable spot is found. When about to oviposit, the fly raises her body and turns the ovipositor and terminal part of the abdomen downward at right angles. The point of the ovipositor is then forced through the skin of the apple, and by an up and down motion inserted the required distance, after which the egg is deposited. After placing the egg, the fly withdraws the ovipositor and walks rapidly around. Usually the ovipositor is still extended and dragging behind; it is then for a moment cleaned or brushed with the hind legs, and drawn back into place. The fly then walks or darts away.

In the numerous observations made in Connecticut the entire egg-laying process has varied in length from about 70 seconds to 7 minutes, which is within the limits noted by previous observers.

The egg puncture (pl. 1, C) is small and irregularly circular in outline. Never very conspicuous, when first made it is very hard to find, but it later becomes brown, and in a light-skinned apple the dark puncture may be seen extending beneath the surface. In dark-skinned apples the punctures are always difficult to find; as they become older the tissue surrounding them becomes corky, and the passageway is often entirely closed. A small quantity of wax is often exuded, frequently forming a tiny bubble at the opening. If the egg is laid in an immature apple the tissue surrounding the puncture grows less rapidly than the rest of the apple, leaving a small dimplelike pit.

The eggs are placed just beneath the skin, at directions varying from nearly a right angle to the surface to nearly parallel with it; in the majority of cases they are placed at angles of 30° to 60° to the surface, and a fair average would be not far from 45°. (Pl. 1, D.)

In some instances a fly will make a puncture and then depart without placing an egg in it. In a few cases two eggs have been found in the same puncture. It is not known whether these were laid at one operation, or at different times by the same fly, or by different flies.

In the early part of the oviposition period the flies seem to be more abundant in trees of the earlier varieties; later they may become equally abundant in trees of fall or winter varieties. The flies leave the ground earlier from beneath trees of earlier varieties, as was pointed out in the discussion of the emergence records, and in the early part of the season the earlier varieties of apple have reached a point where they are more attractive to the flies. As the early fruit matures and drops, the flies present in such trees scatter in search of acceptable fruit.

Ripe fruit seems to have little attraction for the flies, and they seem to pay no attention to fallen fruit. No one seems to have observed the flies on the ground or on fallen fruit, except as they were first emerging from the ground.

The egg-laying capacity of the female flies has never been exactly determined, owing to their exasperating disinclination to oviposit in captivity. Illingworth (*20, p. 143*) found that the two ovaries contain a total of 48 egg tubes, each tube, when mature, containing 4 to 6 eggs in successive stages of development. Since eggs may continue to be developed in the tubes as long as the flies are in healthy condition, it is apparent that the female fly may have a potential capacity of at least several hundred eggs.

LONGEVITY OF THE FLIES

In the matter of longevity, also, the abnormal behavior of the flies in captivity makes it impossible to obtain exact information. The great majority of the flies observed in insectary cages have lived less than two weeks, although in one case one female fly of the first brood lived 51 days, and a male of the same brood lived 47 days. Of the second brood, one female lived 53 days, and two males lived 39 days each. Apparently on account of the cooler weather in the fall the average length of life of flies of the second brood was greater than that of those of the first brood. For the reason just given, detailed records of longevity are of no value and none will be included here.

In the field the flies begin to be noticeably less abundant about one month after the close of the period of greatest emergence. Usually, in Connecticut, they are nearly through emerging by the end of July and have nearly all disappeared from the orchard a month later, although occasional stragglers may be seen until late in September.

PERIOD OF INCUBATION

The period of incubation, as determined by other workers, has varied under different conditions from a minimum of 2 days to a maximum of 10, with averages of from 4 to 7. Illingworth (*20, p. 144*) gives a period of 2 to 6 days, according to temperature; O'Kane (*26, p. 60*) records two observations early in September of 5 days each; Brittain and Good (*3, p. 30*) found in Nova Scotia a period ranging from 5 to 10 days; Caesar and Ross (*5, p. 19*) found that the period for 15 eggs in August, 1912, ranged from 5 to 9 days, with an average of 6.

On account of the scanty oviposition in the insectary at Wallingford, very few additional records can be offered. Four eggs laid in August, 1920, which were not examined until the third day, were found to have hatched, showing that the period is sometimes three days or less. From a number of eggs in apples brought in from the field in the same year, one egg did not hatch until the eighth day after being collected.

Five eggs were laid in the insectary in 1920 and examined daily until hatching occurred. One, laid July 30, hatched 7 days later; 1, laid August 2, and 3, laid August 13, hatched on the fourth day after. The average period for the 5 was 4.6 days. Eleven eggs were laid under observation in the field in that year, the location of each being promptly marked and the eggs examined daily until hatched. Four, laid on August 3, hatched on the fourth day thereafter; 1, laid on

August 9, hatched 5 days later; on August 7 the remaining 6 were laid, of which 3 hatched in 5 days, and of the others 1 each in 3, 4, and 6 days, respectively. For the 11 eggs the average time of incubation was 4.5 days.

LENGTH OF LARVAL FEEDING PERIOD

The rate of development of the maggot is dependent primarily on the rate at which the apple matures, or becomes mellow. This in turn is dependent on the variety, the temperature, whether the apple falls to the ground or remains on the tree, the soil in which the tree is growing, and a multitude of other factors. Illingworth (*20, p. 145*) records a feeding period ranging from 12 to 88 days for 13 larvae in 10 different varieties of apples. In the summer varieties, which become mellow very rapidly, the period may be two weeks or even less, while in hard winter varieties the larvae may not leave the fruit for months. Maggots have been recorded as emerging from apples in storage as late as March, although such records are not the rule. In late fruit the mortality is very high, and virtually all larvae have usually either perished or completed their development and emerged not later than early in winter.

In the work done at Wallingford in 1918 and in 1920 the few eggs which were deposited in the insectary were allowed to hatch without being disturbed, and the maggots completing their development were recorded as they left the fruit. The resulting records, therefore, give only the period from the deposition of the egg to the emergence of the larva from the apple. Since the period of incubation of the egg under ordinary midsummer conditions averages between four and five days, a fair approximation of the larval period might be obtained by subtracting this figure from that for the combined egg and larval period. These records are summarized in Table 3, which presents the maximum, minimum, and average periods for 44 larvae observed in the two seasons, including the varieties of apple in which they were laid.

TABLE 3.—*Period of incubation and larval feeding of apple maggots observed at Wallingford, Conn., in 1918 and 1920*

Variety	Year	Larvae	Period		
			Maximum	Minimum	Average
			Days	*Days*	*Days*
Parker Early	1918	14	20	17	19
McIntosh	1918	27	41	25	31
Red Astrachan	1920	2	21	20	21
Oravenstein	1920	1	28	28	-----------

As it became evident that very few eggs were to be obtained from captive flies, field material was used for determining the duration of the larval feeding period. During the summers of 1920, 1921, and 1922, unhatched eggs were removed from infested apples brought in from the field and transferred to apples which had been bagged since the latter part of June, before oviposition in the field had begun. One egg was placed in a slit in each apple, note was made of the date of hatching, and later of the dates when the mature larvae left the fruit.

After having been transferred to uninfested apples many of the eggs failed to hatch, owing to injury from handling, infertility, or parasitism, and some of the fruit rotted before the maggots could complete their development. Because the fruit had been removed from the tree and the skin was broken for the insertion of the egg, the fruit tissue rapidly ripened and broke down, making conditions most favorable for the development of the maggots. The resulting records, therefore, represent the duration of the larval feeding period under the most favorable conditions, or very close to the minimum period, and give no information as to the possible maximum period. The records obtained are summarized in Table 4.

TABLE 4.—*Feeding period of larvae of the apple maggot transferred to apples for observation, in 1920, 1921, and 1922, at Wallingford, Conn.*

Variety	Year	Larvae	Period		
			Maximum	Minimum	Average
			Days	*Days*	*Days*
Yellow Transparent	1920	2	18	17	18
Red Astrachan	1920	5	20	13	15
Do	1921	5	30	15	18
Gravenstein	1920	17	33	17	22
Do	1921	2	27	17	22
Do	1922	13	34	16	23
Porter	1920	18	29	18	22
Do	1922	22	32	21	25
McIntosh	1921	9	48	24	29
Baldwin	1922	18	33	19	25

MORTALITY IN THE FRUIT

A high average mortality attends the insect during the period spent by it in the fruit. Some of this occurs in the egg stage, owing partly to failure of the eggs to hatch, apparently an unimportant factor, and partly to parasitism, which is also ordinarily unimportant, but may occasionally reach 30 per cent.

The greater part of the mortality in the fruit, however, occurs in the larval period. The factors already noted as unfavorable to rapid development of the larvae within the apple also tend to bring about a high mortality among them. The percentage of survival depends chiefly on the mellowness of the fruit after the larvae hatch, and the readiness with which the flesh of the apple may be broken down. The combined egg and larval mortality has been noted by different observers as varying from about 20 per cent in early drops of early varieties to 100 per cent in winter apples which remained on the tree until picking time.

Data were secured at Wallingford with fallen fruit of two varieties. The mortality in egg and larval stages together was 48 per cent in the case of 82 Wealthy apples containing 127 egg punctures, and 62 per cent with 71 Gravenstein apples containing 295 punctures. Records of this kind can never be exact, since it is impossible to be sure that every egg puncture has been found, and it is impossible also for one to be certain that each egg puncture contained one egg and only one. With picked fruit of the same varieties the mortality would undoubtedly have been greater, and in many of the hard winter varieties almost no larvae would manage to reach maturity. Comparatively few flies are ever obtained from soil cages in which winter fruit has been used as a source of material.

EMERGENCE FROM THE FRUIT

By the time the maggot becomes mature, the apple in which it has been feeding has usually fallen, although in a very few instances apples with the characteristic exit holes have been noted still clinging to the tree, the apples having apparently become mellow enough before dropping to permit the larva to come to maturity. In emerging, the maggot makes its way through the skin by an irregular opening just large enough to allow the passage of its body, leaving a more or less irregular hole with frayed edges of skin at its margin. Cases similar to that mentioned by O'Kane (*26, p. 81*), of a larva which has been unable to proceed after forcing its body half through the opening, have been occasionally noted in Connecticut. Emergence seems to occur at any point in the surface of the apple, and not necessarily on the side toward the ground.

In August, 1918, the emergence of maggots from heavily infested summer apples was recorded at 7 a. m., 12 m., and 4 p. m. The records of emergence are summarized in Table 5.

TABLE 5.—*Emergence of apple maggots from heavily infested summer appl es observed in August, 1918, at Wallingford, Conn.*

Date	Emergence observed at—			Date	Emergence observed at—		
	7 a. m.	12 m.	4 p. m.		7 a. m.	12 m.	4 p. m.
Aug. 3	----------	6	0	Aug. 10	93	34	10
Aug. 4	32	4	2	Aug. 11	111	67	8
Aug. 5	20	3	([a])	Aug. 12	68	22	5
Aug. 6	([a])	([a])	6	Aug. 13	52	25	4
Aug. 7	73	29	7	Total	539	323	63
Aug. 8	35	59	7				
Aug. 9	53	74	14				

[a] No observations. The trays were cleared Aug. 6, at 12 m., and observations resumed at 4 p. m. on the same date.

A study of these data shows that the larvae may emerge at any time of the day or night, but that most of them emerge in the night or in the early part of the day. They do not seem to emerge freely into strong light. Infested apples kept in glass jars have been found with exit holes fully formed before any maggots had emerged. The apparent explanation of this seems to be that on breaking through the skin of the apple the maggot found the light too strong, and retreated again to the interior of the fruit. In the fall, low temperatures in the night seem to cause a suspension of activities, and emergence then apparently takes place mainly in the early part of the day.

In New Hampshire, O'Kane found the greater part of the emergences taking place between 6 a. m. and 6 p. m. The difference between these observations and those made in Connecticut may have been caused by differences in conditions of light or of temperature.

Occasionally a few larvae do not leave the fruit, but form their puparia within it, especially, as Illingworth (*20, p. 146*) has noted, when the apple is dried up from an attack of rot.

ENTERING THE GROUND

On emerging from the apple, the one impulse of the maggot seems to be to get away from the light. Forty larvae, placed in the center of a tray darkened at one end, and in light at the opposite end, were found 10 minutes later all crawling toward the darkened end. Half an hour later a few of them were moving toward the light end of the tray, but along an edge, where a shadow was cast. Under favorable conditions little time is lost in entering the ground. In one instance 26 larvae which had emerged within an hour were placed on loose, moist soil, and nearly all of them were out of sight within 10 minutes, and all had disappeared into the soil in 15 minutes. In another instance 27 larvae all entered the ground within 5 minutes of the time they were placed on it. When placed on dry, powdery soil, the maggots have some difficulty in entering it, and some of them form puparia on the surface.

Information was obtained in 1921 and 1922 regarding the depth to which the larvae entered the ground for pupation. A soil cage was so constructed that layers of soil 1 inch thick were separated by screens having a mesh of one-quarter inch, so that the layers could be removed separately. In each year the cage was filled with sandy loam, and infested apples were placed on the surface. This permitted the maggots to enter the soil normally. The cage was dug up some time afterwards, and the successive layers of soil were examined for puparia. Table 6 gives for each year the numbers of puparia found at different depths, and the corresponding percentages of the total number found. In each year a majority of all had penetrated not more than an inch below the surface, although the percentages of those found in the uppermost inch of soil differed greatly in the two years. Except for a single maggot, none penetrated to a greater depth than 4 inches, although the soil was examined to a depth of 10 inches, at which depth the solid bottom of the cage would have prevented the maggots from going deeper.

TABLE 6.—*Numbers and percentages of puparia found in 1921 and 1922 at stated depths in soil cages, arranged to show the depths reached by the maggots*

Depth (inches)	Puparia		Percentage of puparia at different depths		Depth (inches)	Puparia		Percentage of puparia at different depths	
	In 1921	In 1922	In 1921	In 1922		In 1921	In 1922	In 1921	In 1922
0 to 1	119	450	91.5	51.7	3 to 4	1	3	0.8	0.3
1 to 2	9	315	6.9	36.2	4 to 5		1		.1
2 to 3	1	101	.8	11.6	5 to 10				

Data obtained by different investigators regarding the depth to which larvae may enter the soil for pupation have varied considerably. Brittain and Good (*3, p. 40*) report that in heavy clay 5 per cent of the larvae were found at the bottom of a cage containing 12 inches of soil, and that some of these would doubtless have gone to a still greater depth if it had been possible for them to do so. In sandy soil none of the larvae went to a greater depth than 5 inches. In all of these records comparatively few larvae exceeded that depth, and the greater majority were found within 2 or 3 inches of the surface.

PREPUPARIAL PERIOD

For convenience, the term "prepuparial period" is used here to designate the interval between the emergence of the larva from the fruit and the formation of the puparium. During this interval the maggot ceases its activity and gradually becomes shorter; the skin gradually hardens, turns yellow, and then brown. Whatever the spot the maggot is able to find for the purpose, the puparium is formed not very long after emergence from the apple. The transformation has been noted at Wallingford within 2 hours from the time the larva left the apple; in occasional cases 18 hours elapsed before the puparium was formed; but in the majority of cases the process was complete in from 6 to 11 hours after emergence, whether the maggot had been able to enter the ground or not.

PUPATION

Actual pupation within the puparium takes place within three to five days after the larva enters the ground. This interesting process has been described in detail by Snodgrass (*41*).

SECOND BROOD

The emergence of flies in the fall from material which had entered the ground in the same season was first recorded by Illingworth (*20, p. 147*) in the State of New York. In the warmer part of Ontario, Caesar and Ross (*5, p. 22*) observed the emergence of two second-brood flies from a cage in which had been placed infested Early Harvest apples, but express the opinion that in their section the second brood must be a very small one. Emergence in the same season as that of the entrance has also been observed in Pennsylvania (*6*).

In southern Connecticut flies of a second brood have appeared every season, the total number varying a great deal. Detailed emergence tables will not be given, but the data are summarized as follows:

In 1917, 57 flies appeared from summer-fruit material in 3 cages, from September 25 to October 28.

In 1918 a total of 455 flies appeared in 6 cages of summer-fruit material, between September 10 and November 18. Most of the flies appeared between September 14 and October 1, although a few appeared almost every day throughout the period.

In 1919 the second brood was represented by a single fly, which appeared October 11.

In 1920, 25 flies appeared in 4 cages of summer fruit, from September 25 to October 26.

In 1921, 59 flies appeared in 3 cages of summer fruit and 48 in 13 cages of fall fruit. One fly appeared September 3, one on November 20, and the remainder appeared from September 14 to November 4.

In 1922, a total of 6 flies appeared at intervals from September 28 to October 9.

SIGNIFICANCE OF THE SECOND BROOD

The emergence of flies at the time when the second brood has appeared in Connecticut is very untimely, and constitutes a factor decidedly to the disadvantage of the species. The records show that few of the flies leave the ground before September 20. Allowing at least 10 days for the development of the eggs in the ovaries of the flies during the cooler weather late in September, it is evident that almost none of the flies could be ready to deposit eggs before October, and that many of those emerging later would not mature any eggs until nearly November. Since the flies of the second brood emerge from puparia of the larvae which hatch from eggs laid early in the season, almost entirely in the earlier varieties of apple, the flies on emerging find no fruit for oviposition in the trees where their larval stages were spent, but must search for suitable fruit elsewhere. By October nothing is left except the hard, winter varieties, most of which are unattractive to the flies, and all of which are unsuited to the development of the maggots. Even if oviposition should occur, most of the fruit is harvested and placed in storage before the larvae have reached very great size, which places the maggots under conditions still more unfavorable to successful development. Under the circumstances just outlined, very few eggs will be laid by second-brood flies and only rarely would it be possible for a second-brood maggot to reach maturity. The scarcity of the species in the southern part of its range and its apparent failure to establish itself in new southern localities may be because of a tendency to emerge in the same season too late for oviposition.

In the case of a heavy second brood the proportion of individuals remaining in the ground for two seasons seems to be reduced. In some seasons this would constitute an additional factor unfavorable to the species.

TWO-YEAR CYCLE

The fact that some of the apple maggots remain in the ground as pupae through two winters was first observed independently by Ross (*35*) and O'Kane (*26, p. 84*) in 1913, and their observations have been repeatedly verified by others. The emergence of flies in the second year after the maggots had entered the ground occurred regularly at the Wallingford station.

For the most part these flies appeared during the usual emergence period of one-year cycle flies from similar material. Since the number of two-year cycle flies was ordinarily small, detailed emergence records are not given.

The two-year cycle operates definitely to the advantage of the species, insuring the survival of at least a few individuals over seasons of complete crop failure.

A few of the cages were examined regularly during the third season after the material was placed in them for flies of a possible three-year cycle, but none appeared.

PROPORTION OF EMERGENCE OF FLIES IN RESPECTIVE SEASONS

The percentages of flies which emerged at Wallingford from the different groups of cages as second-brood flies, flies of the usual one-year cycle, and two-year flies, respectively, are presented in Table 7. Second-brood flies emerge almost exclusively from material from early fruit, and when the second brood is a large one apparently a smaller percentage of flies remain in the ground over two winters. The proportions of flies in the different cycles vary considerably with changes in seasonal conditions and with different kinds of fruit.

TABLE 7.—*Percentages of emergence of flies of the apple maggot in the different kinds of broods and under varying conditions, at Wallingford, Conn., from material placed in the cages in 1917, 1918, 1919, and 1920*

Lot	Number of cages	Year fruit was gathered	Season of fruit	Location of cages	Number of flies	Percentage of emergence of— Second brood	Main brood	2-year cycle
A	2	1917	Summer	Sun	935	5.6	94.3	0.1
B	1	1917	do	Partial shade	190	2.6	97.4	-------
C	2	1917	Fall	do	434	-------	67.3	32.7
D	2	1917	do	Sun	164	-------	81.1	18.9
E	6	1918	Summer	Partial shade	937	48.6	49.7	1.7
F	6	1918	Fall	do	38	-------	94.7	5.3
G	1	1919	Summer	Sun	56	-------	96.4	3.6
H	1	1919	do	Partial shade	59	1.7	91.5	6.8
I	3	1919	Fall	Sun	32	-------	62.5	37.5
J	7	1919	do	Partial shade	284	-------	93.0	7.0
K	2	1919	Winter	do	25	-------	88.0	12.0
L	4	1920	Summer	do	172	14.0	77.9	8.1
M	17	1920	Fall	do	1,180	.1	77.7	22.2

NATURAL ENEMIES

The apple maggot seems to be less subject than many insects to attack by predacious and parasitic enemies, owing no doubt to the fact that throughout most of its life cycle it is not easily accessible.

PREDATORS

Occasional flies are captured by various species of spiders. In the soil cages flies are not infrequently found which have been captured by spiders, and such captures may occur in the field as the flies are leaving the ground. Brittain and Good (*3, p. 65*) report observation of a species of spider determined as *Dendryphantes militaris* Hentz, actively capturing flies in the apple trees.

In removing flies from the soil cages at Wallingford on July 4, 1921, one fly was found which was being sucked out by a hemipterous insect, probably a reduviid. The predator was accidentally crushed when captured, and so could not be identified.

As the full-grown maggots are leaving the apples, a few of them are carried away by ants, although the short period which elapses before the maggots have entered the ground gives at this time only a brief opportunity for ants or other enemies. Doubtless, when opportunity offers, other predators, including birds, feed to a limited extent on larvae, pupae, or adults, but the degree of control effected by all such agencies together is apparently incidental and relatively unimportant.

EGG PARASITE

In the season of 1920, in removing for study eggs from infested apples brought from the field, C. H. Alden noticed that a number of them were parasitized. Adults of the parasite were determined by A. B. Gahan as *Anaphoidea conotracheli* Girault, a common egg parasite of the plum curculio, also recorded as a parasite of the eggs of the grape curculio. A short note dealing with it has been published (*32*). The abundance of this parasite would presumably depend in part on the abundance of its other principal host, the plum curculio, in the eggs of which the parasite doubtless breeds before eggs of the apple maggot are available. In an uncared-for orchard near the Wallingford station, where the plum curculio was very abundant, between 25 and 30 per cent of the eggs of the apple maggot were parasitized. In commercial orchards the reduction of the curculio infestation by spraying and by other practices undoubtedly also limits the numbers of this parasite.

LARVAL PARASITES

Opius melleus Gahan (*Biosteres rhagoletis* Richmond) was reared in Maine in 1914 from puparia of the apple maggot by Woods (*47*), who also swept specimens of it in blueberry barrens; in the same year, also in Maine, Severin (*47*) bred the species from puparia of the apple maggot, obtained from either wild crab or cultivated apple. The following year the same parasite was observed by Good (*16*) in Nova Scotia, ovipositing in maggots in the fruit.

The parasite oviposits in the maggots in the host fruit; the maggot matures, enters the ground, and forms its puparium as usual, from which the adult parasite emerges in the following summer. Brittain and Good (*3, p. 65*) express the belief that this parasite is not of great importance.

In 1922 a few adults of the parasite *Opius ferrugineus* Gahan appeared in the soil cages at Wallingford, and one individual appeared in a battery jar into which sifted earth and apple maggots and puparia had been placed in 1921. This one emergence indicated definitely that these parasites emerged from apple-maggot puparia, and not from any foreign material which easily may have been present in the out-of-door cages. The parasites appeared from July 22 to August 22, several weeks after the peak of the emergence of the flies. Apparently the parasite has one generation a year, and emerges just before the host maggots are present in the fruit in greatest numbers.

A few of these parasites were confined in cages with heavily infested apples. A number of the apple maggots were later found to contain parasite larvae, presumably from eggs laid by the parasites confined with them. The closing of the Wallingford station prevented further studies of this enemy of the apple maggot. Probably the egg is deposited directly in the host larva, in which case parasitism would be limited to those maggots which chanced to come within reach of the parasite's ovipositor, which is less than one-fourth of an inch in length. The greater size of the recently acquired host fruit, the apple, has doubtless rendered the maggots less subject to attack by this enemy, which is probably able to reach a high percentage of its victims in the smaller fruits, such as haws, blueberries, and huckleberries.

A total of 45 parasites emerged from soil cages containing material from two sources near Wallingford, and from one lot of material from Milford. From these same cages emerged 950 flies, which means a parasitism of less than 5 per cent. In the battery-jar cages in which one parasite emerged 306 flies appeared. Since this parasite was encountered only once in five years, and then gave a very low proportion of parasitism, it is at present obviously of minor importance. With the number of maggots which can be attacked severely limited by the length of the parasite ovipositor, it is doubtful if much may be expected from this enemy.

CONTROL MEASURES

Until very recent years the apple maggot has been a most difficult insect to control. Many possible methods of control have been suggested and tried. Some of these have had little or no value, others have had some value, but none of them had given complete satisfaction.

SPRAYING

Mention has already been made of the habits of the flies, which feed in the same manner as do house flies, which are able to absorb even dry solids by bringing them into solution or fine suspension by means of a drop of liquid which is forced out of the proboscis and later sucked back again. The practical possibilities in these habits were overlooked until very recent years.

In 1888 Augur (*1*) observed in Connecticut that some growers who sprayed thoroughly with arsenicals for the codling moth had little trouble with the maggot, and in 1896 Kinney (*21*) reported from Rhode Island that very little injury by the apple maggot occurred in the case of trees heavily sprayed with Bordeaux mixture and Paris green during the period when the fruit was growing. Whether these were coincidences or cases of actual control is impossible to determine, but the possibilities in the use of arsenicals for the control of the apple maggot were not generally appreciated at the time.

In an earlier portion of this bulletin has been traced briefly the history of the development of the use of lead arsenate for the control of the apple maggot, from Illingworth's first tests with the sprinkling of small quantities of sweetened arsenicals in the trees to the work with arsenate of lead, applied in the usual manner, which followed in Nova Scotia, Ontario, and New York. The more recent experiments were being reported on as the writer's work in Connecticut was getting under way, and the first task in the control phase of the investigation became that of demonstrating or disproving the value of the lead-arsenate treatment as a control for the apple maggot.

Numerous efforts were made by the writer to determine by means of insectary tests the effect of arsenate of lead and other poisons on the flies. Several types of cage were used, including large and small screen cages, inverted jelly tumblers, and battery jars. The poisons were offered to the flies on the surfaces of apples and on foliage. Throughout the experiments the abnormal behavior of the captive flies prevented the obtaining of conclusive results, as the flies died with about the same rapidity in all cages, regardless of the presence or absence of poison. Under such circumstances negative results have no particular meaning.

METHODS OF ESTIMATING RESULTS

Throughout the field-control experiments conducted by the writer in Connecticut the same method of estimating results was followed. All of the dropped fruit, and a certain part of the fruit picked from each count tree, was bought from the owner of the orchard, placed in tight cotton bags, examined at frequent intervals, and a record made of the numbers of maggots which emerged. By buying the fruit it was possible to hold it until all maggots had matured and emerged. In many cases one-half of the harvest was used; in a few cases only one-third of it was taken, and in other cases the entire crop from the count trees was bought. Whatever the portion of the harvest taken, the resulting figures were multiplied by the proper factor before being added to the figures for the drops. In this way the final figures represent in each case the entire crop on each count tree. In most cases counts were made on three trees in each treatment.

This seems to the writer to be the most satisfactory method of estimating the results of any treatment for the control of the apple maggot. Superficial examination of the fruit may give little idea of the infestation which may be developing in it. Apples apparently free from infestation at harvest time may develop a great number of maggots and become worthless on being held for a few weeks.

Were it possible to make a satisfactory count of the egg punctures, such a count would be the ideal way of determining results. It is true that some punctures do not contain eggs and that other punctures may contain two eggs, but errors of this nature are to some extent compensating and would have little effect on comparative figures, especially if large counts were made. The vital objection to scoring results by this method lies in the difficulty with which the punctures may be detected, especially in dark-skinned fruit. On several occasions the writer attempted to make counts of egg punctures, all counts being carefully checked by a second person. In many cases a close examination with a binocular microscope would reveal the fact that not more than half of the egg punctures present had been detected, even when the first examination was carefully made with a hand lens, and several minutes spent on each apple. Besides being inaccurate and very slow, the examination of large numbers of apples for the minute and inconspicuous egg punctures is extremely trying to the eyes. For this reason the method of estimating the results by the number of maggots emerging from the fruit was decided upon as the most satisfactory and practicable. The mortality of the maggots in the fruit would doubtless be fairly uniform throughout the same orchard in the case of any given variety. Because of the existence of extreme differences in susceptibility to attack, and in the percentage of mortality which occurs in the fruit, no comparisons were attempted between different varieties in any one series of treatments.

Figures are given representing both the total number of maggots per tree and the relative infestation, expressed as the average number of maggots maturing in each hundred apples. Both ratios have significance, and both are subject to considerable error. The ratios of maggots per hundred apples seem consistently to have somewhat smaller probable errors, which suggests that the flies probably have a tendency to distribute themselves according to the number of apples available on the different trees. That is, the fruit on a tree bearing a heavy crop is frequently as heavily infested with maggots as that on a near-by tree with a light crop. In fact, in many cases the flies seem to concentrate their egg-laying efforts in the trees with the largest crops, although this tendency is not entirely consistent.

The averages of maggots per tree and maggots per hundred apples have been analyzed for probable error, and the probable errors included in the tabulated results of the experiments. The probable error of each average was computed by the well-known formula

$$P.\ E. = \pm 0.6745\sqrt{\frac{\Sigma(d^2)}{n\,(n-1)}},$$

in which $P.\ E.$ is the probable error, n the number of observations, and d the deviation of an observation from the mean.

The percentage reductions in maggots per tree and maggots per hundred apples effected by spraying as recorded in Tables 8 to 11 have been computed from averages of maggots per tree and maggots per hundred apples, as there shown. If $\overline{B}$ represents the average of the maggots from the count trees, or per hundred apples, from a plot which has been sprayed, and $\overline{A}$ the average from the corresponding check plot, the percentage reduction in maggots is

$$100 - 100\,\frac{\overline{B}}{\overline{A}},$$

the reduction being expressed as a percentage of the average for the untreated plot. If b and a are the probable errors of $\overline{B}$ and $\overline{A}$, respectively, the probable error of

$$100 - 100\,\frac{\overline{B} \pm b}{\overline{A} \pm a}$$

is given by [8]

$$\frac{100}{\overline{A}}\sqrt{\left(\frac{\overline{B}a}{\overline{A}}\right)^2 + b^2}.$$

The probable error of the mean of the percentage reductions in maggots per tree and that of the mean of percentage reductions in maggots per hundred apples (omitting treatments with spray containing molasses), as given in Table 8, were calculated by the formula

$$P.\ E. = \frac{\sqrt{e_1{}^2 + e_2{}^2 + e_3{}^2 + \ \ldots\ e_n{}^2}}{n}$$

in which $P.\ E.$ is the probable error of the mean, n the number of percentage reductions averaged, and e_1, e_2, etc., are the respective probable errors of the different percentage reductions.

EARLIER EXPERIMENTS

Field experiments were begun in 1919 and continued through 1922. From the outset an effort was made to have the unsprayed plats somewhat isolated from the treated blocks, but the extremely critical importance of this precaution was appreciated more fully later.

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[8] The formula

$$\frac{1}{A}\sqrt{\left(\frac{Ba}{A}\right)^2 + b^2}$$

is regularly used for deriving the probable error of the quotient when the divisor A and the dividend B are each affected by a probable error, designated, respectively, by a and b; and a little consideration will show that the probable error of the percentage reduction is that of $\frac{\overline{B} \pm b}{\overline{A} \pm a}$, identical with that of the quotient of these quantities, expressed as a percentage. This and the other formulas here used can be found in works on the theory of errors.

Apparently because of insufficient distance between sprayed and unsprayed plats, some of the earlier experiments were inconclusive, but for the sake of completeness summaries of their results are given in Table 8. In addition to the experiments summarized in this table, another series, begun in an orchard near Milford, Conn., in 1920 and continued through 1922, is treated in greater detail elsewhere in this bulletin. In all of the earlier experiments the materials were applied twice, the first application being made early in the emergence period of the flies, and the second two to three weeks later.

On the basis of the total number of maggots developing, this series as a whole shows a percentage reduction in the treated plats of a little more than twice its probable error, which is not significant. On the other hand, on the basis of the number of maggots developing in every 100 apples, the reduction was about eight times its probable error, and may therefore be considered significant. However, even considering the data significant, the degree of control secured was not satisfactory. In the belief of the writer this failure to secure better control was due to the fact that the unsprayed portions of the orchards were too near to the sprayed portions. Although the infestations in most of these tests were not heavy, the series as a whole may be taken as giving at least a clear indication that the treatment with lead arsenate has some value in the control of the apple maggot.

EXPERIMENTS AT MILFORD

Experiments carried on in 1920, 1921, and 1922, in an orchard near Milford, Conn., were conducted under much more satisfactory conditions. Well-isolated blocks were possible in this orchard, and there was a much more severe maggot infestation.

Figure 7 gives a plan of the orchard, which consists of approximately 17 acres of trees about 26 years old, lying on nearly level land, on both sides of a fairly broad highway which runs north and south, about 9 acres of orchard being on the east side and 8 acres on the west side. On the west side the varieties are as follows, beginning at the south: Baldwin, 3 rows; Rhode Island Greening and Smokehouse, 2 rows; Gravenstein, 2 rows; McIntosh, 4 rows; Rhode Island Greening and Smokehouse, 2 rows; Baldwin, 2 rows; Hurlbut, 2 rows. On the east side of the road the orchard is divided into three blocks, each containing 4 rows of Baldwins and 4 or 5 rows of Rhode Island Greening and scattered Smokehouse trees.

The variety used in these experiments was the Smokehouse, sometimes called the Red Vandevere, which had been planted accidentally among the Rhode Island Greening trees. In this orchard this variety has been very severely attacked by the apple maggot, and the owner has in past years made a practice of picking the fruit several weeks before the normal ripening season, and selling it for what it would bring in that condition, rather than leave it for the maggots to ruin completely. According to the owner, the infestation was fairly uniform throughout the orchard.

The fact that the Smokehouse trees were scattered among different blocks of Rhode Island Greening over the 17 acres of orchard made possible a reasonable isolation of the different blocks, especially when the sprayed and unsprayed trees were on opposite sides of the highway. The fact that the two portions of the orchard were opposite each other for only a short distance along the road, and that through-

TABLE 8.—*Results of experiments in the control of the apple maggot in Connecticut in 1919, 1920, and 1921*

Year	Locality	Variety	Material	Count trees	Total number of apples	Total number of maggots	Maggots per tree	Maggots per 100 apples	Percentage reduction (−) or increase (+) in—	
									Maggots per tree	Maggots per 100 apples
1919	Wallingford	Gravenstein	Arsenate of lead 1-50 [a]	5	1,820	114	22.8±4.2	6.3±0.9	−84.8±4.7	−84.1±3.0
	do	do	Arsenate of lead 1-50+molasses 1-50 [b]	5	2,330	213	42.6±12.9	9.1±2.7	−71.6±11.2	−77.0±7.4
	do	do	Check	5	1,893	750	150.0±37.6	39.6±4.9		
1920	do	Red Astrachan	Arsenate of lead 1-50	3	917	20	6.7±2.7	2.2±0.8	−87.9±5.5	−79.8±7.5
	do	do	Check	3	1,528	166	55.3±11.1	10.9±0.8		
	do	Gravenstein	Arsenate of lead 1-50	3	1,675	133	44.3±25.9	7.9±1.9	+39.7±87.5	−16.0±22.9
	do	do	Check	3	1,014	95	31.7±7.1	9.4±1.2		
	Deep River	do	Arsenate of lead 1-50	3	2,142	296	98.7±29.8	13.8±2.6	−18.6±26.1	−54.2±12.0
	do	do	Check	3	1,210	364	121.3±13.0	30.1±5.5		
1921	Kensington	Wealthy	Arsenate of lead 1-50	3	2,207	638	212.7±71.4	28.9±8.8	−48.5±18.8	−41.7±18.6
	do	do	Check	3	2,496	1,239	413.0±59.1	49.6±4.7		
Mean of percentage reductions by all treatments with arsenate of lead 1-50 (without molasses)									−40.0±18.7	−55.2±6.6

[a] 1 pound of powdered arsenate of lead in 50 gallons of water.

[b] 1 gallon of molasses in 50 gallons of water.

out this short distance the trees on the east side were Baldwin, which is not especially attractive to the flies, made the separation of the two portions all the more complete.

In 1920 all the Smokehouse trees on the east side of the road were sprayed with powdered lead arsenate, 1 pound in 50 gallons of water.

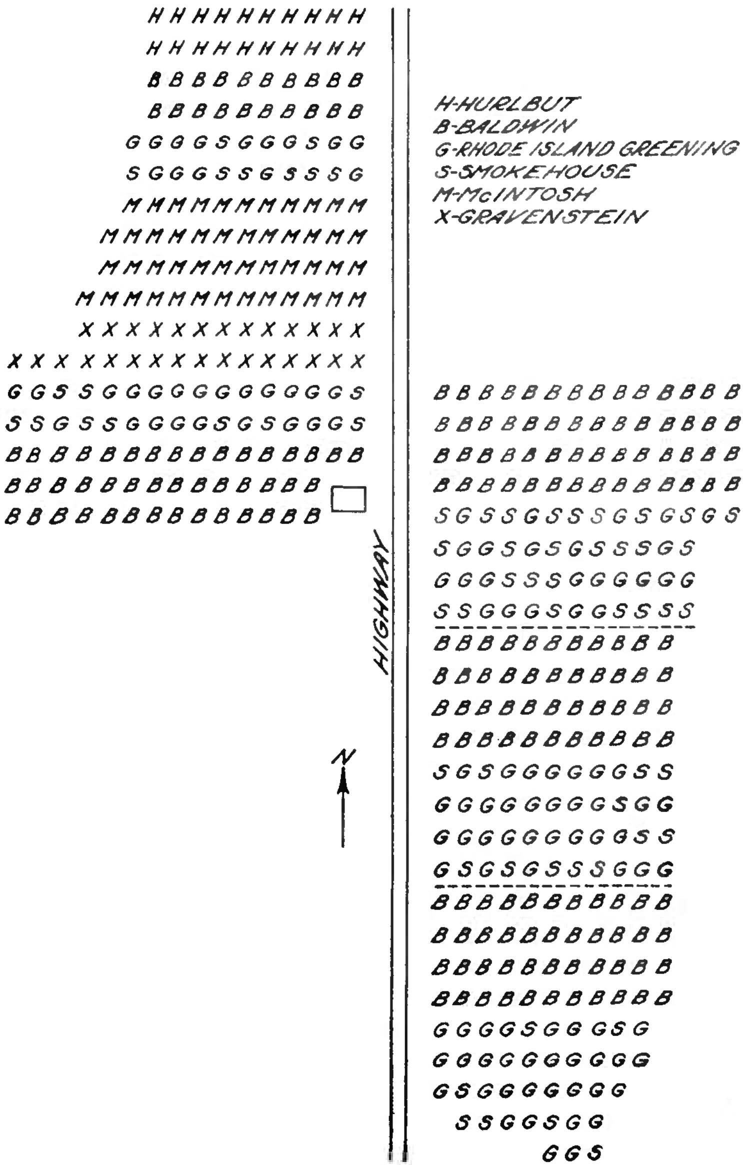

FIG. 7.—Plan of experimental orchard, Milford, Conn.

The applications were made July 16 and August 4, with a power outfit, a spray gun being used from the ground. The late date of application was due to the lateness of the emergence of the flies that season, and to the fact that only fall and winter varieties were present in the orchard. The results of this season's work are summarized in Table 9. The treatment resulted in the destruction of more than 80 per cent of the flies as indicated by either the number of maggots developing in the crops on each tree or in each hundred apples.

TABLE 9.—*Results of experiments in the control of the apple maggot at Milford, Conn., in 1920*

Portion [a] of orchard	Treatment	Count trees	Total number of apples	Total number of maggots	Maggots per tree	Maggots per 100 apples	Percentage reduction in—	
							Maggots per tree	Maggots per 100 apples
East side, north block.[b]	Powdered lead arsenate, 1 pound to 50 gallons of water.	3	4, 583	906	302±98. 9	19. 8±4. 7	83. 3±5. 7	80. 7±4. 9
West side	Check	3	5, 300	5, 439	1, 813±174. 3	102. 6±9. 6		

[a] See fig. 7. [b] The count trees were in this block.

Because of the possibility that the infestation might not have been uniform throughout the orchard, the plats in 1921 were rearranged to include both sprayed and unsprayed trees on both sides of the road. In the north block on the east side of the road the Smokehouse trees, as in the previous year, were sprayed with dry lead arsenate, 1 pound in 50 gallons of water; in the south block with a homemade paste lead arsenate at an equivalent strength; and the middle block was left untreated. On the west side of the road about half of the Smokehouse trees were treated with lead arsenate, 1 pound in 50 gallons of water, and the remainder of the trees were left as checks. At the time it was thought that the Smokehouse trees were sufficiently well isolated, scattered as they were among the much less susceptible Rhode Island Greening, in turn separated by blocks of Baldwin, likewise only slightly susceptible to maggot attack.

The first application was made July 2, but rains occurred before the material was completely dry and the application was repeated July 8. Another application was made July 26.

The results of these tests are summarized in Table 10. Since the three sprayed plats received virtually the same treatment, and the unsprayed plats were also under similar conditions, the figures have not only been given separately but have been assembled as if the three treated plats were one, and as if the two check plats were one.

TABLE 10.—*Results of experiments in the control of the apple maggot at Milford, Conn., in 1921*

Portion [a] of orchard	Treatment	Count trees	Total number of apples	Total number of maggots	Maggots per tree	Maggots per 100 apples	Percentage reduction [b] in— Maggots per tree	Maggots per 100 apples
East side, north block.	Powdered arsenate of lead 1-50.	3	3, 245	3, 524	1, 175±184. 0	108. 6±4. 7	42. 9±9. 8	54. 3±2. 9
East side, south block.	Paste arsenate of lead, equal to powdered arsenate of lead 1-50.	3	3, 078	4, 158	1, 386±255. 7	135. 1±10. 3	32. 6±13. 3	43. 1±5. 1
East side, middle block.	Check	3	2, 596	6, 167	2, 056±141. 6	237. 6±11. 2		
West side, treated.	Powdered arsenate of lead 1-50.	3	2, 318	2, 964	988±229. 7	127. 9±28. 7	62. 4±9. 3	52. 8±11. 2
West side, not treated.	Check	3	2, 907	7, 874	2, 625±214. 9	270. 9±21. 3		
Total treated.	Arsenate of lead 1-50.	9	8, 641	10, 646	1, 183±119. 1	123. 2±9. 3	49. 4±6. 0	51. 7±4. 3
Total not treated.	Check	6	5, 503	14, 041	2, 340±143. 6	255. 2±12. 2		

[a] See fig. 7.　[b] Compared with nearest check.

The data in Table 10 bring out the fact that the normal infestation was reasonably uniform throughout the orchard. The control obtained was much poorer than that of the previous season; the difference was doubtless caused by the fact that the sprayed and unsprayed blocks were much nearer to each other than in the preceding year. This correlation seems evident, although all unsprayed trees were at least four or five trees distant from the sprayed and were further isolated by the less susceptible varieties among which they were planted.

In 1922, in order to minimize the influence of the migration of the flies, the entire orchard east of the road was sprayed, including in addition to the Smokehouse trees the Rhode Island Greening and Baldwin, which are much less susceptible to the attack of the apple maggot, and many of which bore little or no fruit. The three similar blocks on this side were given slightly different treatments, although it was realized that the results in the respective plats would probably be subject to more or less modification on account of the movements of the flies from tree to tree, and that for this reason any differences between adjoining plats would have to be interpreted with caution. The north block was treated with powdered lead arsenate, 1 pound in 50 gallons of water; the south block with arsenate of lead, 1½ pounds in 50 gallons; the middle block with the same, having in addition a commercial casein-and-lime spreader. The part of the orchard west of the road was used as a check. This block had been used by the Connecticut Agricultural Experiment Station for experiments with spraying and dusting, but only a very small amount of spraying had been done later than June, and that was confined to the two rows next to the road, which, if it had any influence at all, would have served as a partial barrier to the movements of the flies from one side of the road to the other. All check-count trees were taken in parts of the orchard which had received neither dust nor liquid spray in July.

The first application was begun July 1, but rain fell nearly every day for more than a week, and the first spraying was not completed until July 10, although it was virtually finished July 7. The greater part of the second application was made July 24 and 25, and the remainder, a few of the Baldwin trees, were sprayed August 1.

The results of this season's tests are summarized in Table 11. All three treatments gave very satisfactory results, and the differences among them are too slight to have significance.

The progress of the infestation in the different sections of the orchard, under different treatments during the three seasons, may be of interest, and is therefore summarized in Table 12, which includes data from the sections of the orchard where such information was available.

TABLE 11.—*Results of experiments in the control of the apple maggot at Milford, Conn., in 1922*

Portion of orchard [a]	Treatment	Count trees	Total number of apples	Total number of maggots	Maggots per tree	Maggots per 100 apples	Percentage reduction in— Maggots per tree	Percentage reduction in— Maggots per 100 apples
East side, north block.	Arsenate of lead 1–50.	3	7,480	353	117.7±42.8	4.7±1.1	97.8±1.0	96.8±1.0
East side, middle block.	Arsenate of lead 1–50 plus spreader.	3	5,070	158	52.7±13.8	3.1±0.5	99.0±0.4	97.9±0.6
East side, south block.	Arsenate of lead 1.5–50.	3	9,650	684	228.0±71.5	7.1±1.4	95.7±1.7	95.2±1.4
West side	Check	3	10,788	15,789	5,263±1,293.6	146.4±32.4		

[a] See fig. 7.

TABLE 12.—*Progress of infestation of the apple maggot, with summary of the treatments used, in the orchard at Milford, Conn., in 1920, 1921, and 1922*

Portion of orchard [a]	Year	Treatment	Maggots per tree	Maggots per 100 apples
East side, north block	1920	Arsenate of lead 1–50. Only Smokehouse trees sprayed. No near-by checks.	302	19.8
Do	1921	Arsenate of lead 1–50. Only Smokehouse trees sprayed. Checks in next block.	1,175	108.6
Do	1922	Arsenate of lead 1–50. All varieties sprayed. No near-by checks.	118	4.7
East side, middle block	1921	Check	2,056	237.6
Do	1922	Arsenate of lead 1.5–50+casein-and-lime spreader. All varieties sprayed. No near-by checks.	53	3.1
East side, south block	1921	Arsenate-of-lead homemade paste, equivalent to dry form 1–50. Only Smokehouse trees sprayed. Checks in next block.	1,386	135.1
Do	1922	Arsenate of lead 1.5–50. No spreader. All varieties sprayed. No near-by checks.	228	7.1
West side	1920	Check	1,813	102.6
Do	1921	Do	2,625	270.9
Do	1922	Do	5,263	146.4

[a] See fig. 7.

CONCLUSIONS AS TO SPRAYING

Materials

Commercial powdered arsenate of lead applied in a liquid spray has proved effective for control of the apple maggot in Connecticut whenever other conditions have been satisfactory. A dosage of 1 pound of the arsenate in 50 gallons of water seems sufficient for effectiveness, and it is a question whether increasing the proportion of poison adds to the value of the treatment. The paste form of the arsenate is probably approximately equal in effectiveness to the dry. A spreader may be added if desired. The material should be applied as for the codling moth, and a fairly thorough covering made, particularly with the first application. The second application should bo lighter in order to avoid excessive residue. If it is necessary to spray the fruit too shortly before the fruit is picked, any excessive spray residue should be removed.

The writer has had no field experience in the control of the apple maggot by using combinations of arsenate of lead with lime-sulphur or with Bordeaux mixture, and is therefore unprepared to state whether or not such combinations would be effective. Several other investigators, however, have reported satisfactory control of the apple maggot or of related species with such combinations.

A few reports have been received of satisfactory control of the apple maggot by means of a dust of dry lead arsenate, but the writer has had no opportunity to test this method experimentally. Since dusting leaves less residue than spraying, this method would be of particular value in the treatment of midsummer varieties, which need treatment only a short time before picking.

Timing

The chief consideration in the control of the apple maggot is to keep the foliage and growing fruit covered with spray in the early part of the period when the flies are present in the trees, in order to poison them before they begin to lay eggs. The emergence tables show that in southern Connecticut the flies may begin as early as the middle of June to appear from the earliest varieties and in unusually early seasons, and that after emergence is once well under way it continues for about five weeks. Field observations have indicated that few flies are present after the first part of September. The period during which protection is needed is therefore from the latter part of Juno to the latter part of August. A little time may be allowed at the beginning of the season for the development of the eggs in the ovaries of the flies, but it is unsafe to allow more than a week. Under ordinary conditions this protective coating may be maintained by two applications of the poison. In southern Connecticut the first application should be mado in the latter part of June or the very first days of July. As the fruit continues to grow rather rapidly during July, the second application is usually needed in from two to three weeks after the first. If excessive rains have washed off too much of tho material a third application may be necessary.

Some growers determine the best time for beginning the first application by placing infested apples in cages on the ground in the fall, allowing tho maggots to enter tho ground normally, and watching for the first emergence of flies in the following June or July. In doing this it is essential to use large quantities of heavily infested fruit; if that is not done the flies may fail to appear. If sufficient material is used it is safe to ignore the very first few flies which appear, and wait until flies begin to emerge in fair numbers. Watching until the first flies are seen in the orchard is likely to mislead the grower, unless a very exhaustive search is made, since the flies are often hard to find until they have been emerging for some time.

On the whole, the best method of timing the applications for the control of this insect is to decide upon an arbitrary date for the first application, modifying it to suit the general lateness or earliness of the season. In southern Connecticut the spraying of the earliest varieties of apples should in the average season commence about June 25, and of fall and winter varieties in the first few days of July. These are approximately the same as the dates recommended for New York and for southern Ontario, whereas for northern and eastern Ontario July 7 is recommended (*5, p. 4*). In Nova Scotia the first spray is not needed until the middle of July or later (*3, p. 64*).

Influence of near-by infestations

Untreated infestations in or very near the section of orchard to be protected constitute a factor of critical importance in the control of the apple maggot. Where unsprayed infested orchards are adjacent to an orchard which is sprayed, the value of the treatment is reduced materially. Apparently there is a rather free movement of the flies from tree to tree throughout the orchard and between closely adjoining orchards. The flies evidently move from the untreated orchards into the sprayed trees and oviposit extensively before being killed by the insecticide or returning to the untreated trees.

There is evidence that in orchards of mixed varieties, some of which are much less susceptible to the attack of the apple maggot than others, the flies may spend considerable time in the trees of the less susceptible sorts, especially before oviposition has begun. For best results it is worth while to spray all the trees in the orchard, regardless of susceptibility or the size of the crop, although fair results may in some instances be obtained by spraying the most susceptible varieties only.

Will spraying be successful in all localities?

For some reason not understood, the treatment here outlined has not proved successful in New Hampshire, although workers in regions near that State and in several directions from it have been able to obtain very satisfactory control. There seems to be sufficient evidence, however, that under the conditions prevailing through most of the infested area this treatment will give a reasonable degree of success, provided there is no untreated infestation close to the area to be protected.

Incidental value of spraying for the apple maggot

In much of the area in which the apple maggot is troublesome, the usual spray schedule does not include applications later than June. In New England the fruit is often seriously injured late in the summer and until the beginning of the harvest, by a number of different chewing insects, including leaf rollers, bud moths, and other species. The applications recommended for the control of the apple maggot will incidentally give a material degree of control of many of the insects referred to, and will in many cases be advantageous, irrespective of their value in controlling the apple maggot.

REMOVAL OF DROPS

Before the value of spraying for controlling the apple maggot had been demonstrated, the only satisfactory means of controlling this pest had been the removal and destruction of the fallen apples while the maggots were still in them. Where sufficient labor is available and the cost is not too great this practice is still worth following.

Almost no maggots emerge from the fruit while it is still on the tree, and very few emerge until the apples have been on the ground for at least several days. In a long and careful series of experiments O'Kane (*26, p. 115*) found that almost no maggots will have emerged from the softer varieties of early fruit if the apples are removed twice a week, from harder early varieties and fall fruit if removed once a week, and from late fall and winter apples if removed once in two weeks. The fruit thus removed may be fed to stock, made into cider or vinegar, dumped into a stream or mill pond, or disposed of in any other convenient way, so long as no maggots are allowed to emerge and form puparia where they may successfully transform and emerge as flies in the following season. Burying is ineffective unless the apples are covered with several feet of earth, as flies have been known to emerge from a depth of 2 feet.

In some cases stock is allowed to run in the orchard and consume the fruit as it falls; but very few commercial growers have enough stock to keep a large orchard free from drops, and many object to the presence of hogs and cattle in the orchard.

If not too seriously infested, the fallen fruit of the later varieties may be utilized for cider or vinegar, and its value for such purposes may in many cases more than cover the cost of gathering it.

Aside from the cost and the amount of labor required, this method of control has the disadvantage of having no effect upon the infestation of the current season, and its full effects do not become evident until the second or third season after the practice is begun, owing to the fact that a certain percentage of the insects remain in the ground over two winters.

With this method, even more than with control by spraying, the results will be disappointing if uncared-for infestations are present near by, and every effort should be made to apply the treatment over as wide an area as possible and to eliminate all untreated sources of infestation in the vicinity.

CULTIVATION

Cultivation has sometimes been recommended as an aid in the control of the apple maggot, but its value is problematical. The mere fact of disturbing the insect would seem to have little effect on it, securely inclosed as it is in a hard, compact shell, and independent as it is of the protection of an earthen cell. In the experiments in soil treatment which will be outlined, 82 flies emerged in the first season from 114 puparia which had been sifted out of the soil in which they had been formed, placed in soil in wire cages, buried again, treated with sodium cyanide, dug up again, and again buried. As a matter of fact, cultivation seems on the whole to render soil conditions favorable to emergence of the flies. In several of the experiments in soil treatment which are on record, a greater proportion of flies emerged from cages in which the soil had been frequently stirred than emerged from cages in which the soil had been undisturbed. Relatively fewer flies emerged where the soil had been made compact and hard, but such a condition does not fit in with the best orchard practice.

Ordinary cultivation fails to bury the puparia sufficiently deep to prevent the emergence of the flies; as stated before, they have been known to emerge from a depth of 2 feet. The chief direct value of cultivation would seem to be in the number of puparia which may be exposed to birds and to various predacious insects. The space directly underneath the tree, however, where puparia are present in greatest numbers, usually receives the least cultivation, especially if the branches are low. The indirect influence of cultivation on the apple-maggot infestation may be greater than its direct effect upon the puparia. Cultivation has a tendency to delay the ripening of the fruit, thereby increasing the mortality of the maggots in it. Such a decrease in the number of maggots which come to maturity might in a few cases mean the difference between a fairly marketable crop and one which is virtually worthless.

INEFFECTIVE OR IMPRACTICAL MEASURES

ATTRACTIVE SUBSTANCES

Consideration has been given to the possibility of finding some substance which could be utilized to draw the flies into a trap, or to a poison if the attractive substance were not in itself poisonous.

Apple odors

Effective attractants might be expected among the odorous constituents of the apple. Samples of such materials were obtained through the courtesy of the Bureau of Chemistry, and were tried on the flies at Wallingford, both in cages and in the field. The materials tried were amyl acetate, undiluted and in dilutions of 0.1 and 0.001 per cent in water; iso-amyl *n*-caproate, undiluted and in dilutions in water of 0.1 and 0.01 per cent; acetaldehyde in full strength and diluted to 0.1 per cent; and amyl formate at similar strengths. The results were negative in all cases, no flies being attracted.

Sweets

Although many flies and other insects are attracted to sweets, the apple-maggot flies seem to evidence no such response. A long list of sweets were exposed to the flies in cages and in the field, undiluted and in dilutions of 10 per cent and 1 per cent; cane sugar, a weak solution in water; honey, a 5 per cent solution; fructose sugar, a 10 per cent solution; glucose sugar, a 10 per cent solution; whey, which would contain a small proportion of lactose sugar; and saccharine, 1 grain in 1 quart of water. None of these attracted more than an occasional fly.

Crushed fruit and fruit juices

The juice and pulp of crushed apples, both sweet and fermented, were offered to the flies, but no attraction to them was shown. Similar results were obtained with the pulp and juices of lemons and oranges.

Other substances

A few other substances also gave negative results. These included kerosene, gasoline, citronella oil, glycerin solution, and formalin in dilute solution.

Other workers have been similarly unable to attract the apple-maggot flies in numbers to any materials. This work is reviewed in detail by Severin (*39*), who includes a list of some 40 materials which he tested without success. Ross (*34, p. 68*) captured a few flies in kerosene and crude petroleum, but in tests by others the same substances have given results entirely negative.

SOIL INSECTICIDES

In experiments in treatment of the soil with insecticides to kill the apple-maggot pupae, Ross (*34, p. 69*) tried a number of materials, including copper sulphate, kerosene emulsion, lime-sulphur, brine, pyrethrum, and several proprietary materials. None of the tests gave encouraging results except when the materials were used in excessive strengths or quantities. Similar negative results are reported by Brittain and Good (*3, p. 45*).

The writer on two occasions in 1921 tried treatment of soil with sodium cyanide. Small lots of healthy pupae, of 12 each, were placed in small wire cages and buried, some 1½, and others 3, inches deep in soil, which was then treated with sodium-cyanide solution. The solution was made in two strengths, one-eighth ounce and three-sixteenths ounce each, in a gallon of water, and was applied at the rate of 1 quart per square foot. A solution of each strength was applied separately to soil containing pupae buried at each of the two depths. One of the two tests was begun June 24, when the soil was rather dry, and the other June 27, when the soil was thoroughly wet after a rain. At the time of the treatments the temperature of the soil at a depth of 2 to 3 inches was not far from 70° F.

On July 6 the puparia were removed from the wire cages in which they had been buried, and were placed in small soil cages for emergence. Detailed records of emergence will not be presented, but approximately three-fourths of all puparia yielded flies the first season, irrespective of treatment. The number of flies emerging in the first season was sufficient to show that the treatment was without value.

SUMMARY

The apple maggot is a native American insect, which until about the middle of the nineteenth century confined its attacks to native fruits, chiefly, it would seem, to the hawthorn. During the past 75 years or so its attention has been turned to the cultivated apple, and the insect is now a major pest of the apple in the northeastern part of the United States and in southeastern Canada.

Besides the apple and the hawthorn, the species sometimes attacks pears and plums, and possible cherries; and in certain localities blueberries and huckleberries also. Although the flies reared from the different host fruits can not be distinguished one from another, it seems very possible that some of the different forms of them are biologically distinct, and that the insects from one host do not normally attack another host unless the two fruits are closely similar.

A little injury is done by the flies in laying their eggs, but the serious damage is caused by the maggots, which, in feeding and moving through the fruit, break down the pulp, leaving brown trails of rotten tissue. If several maggots are present in one apple it may be completely honeycombed.

The apple maggot is found in the southern part of Canada, and in the United States from Nova Scotia and New England across the northern tier of States into the Dakotas, southward along the Allegheny Mountains into North Carolina, and has been found in small numbers in Kansas and in northwestern Arkansas. Its range as a serious apple pest extends from the region of the Great Lakes eastward through Ontario, New York, New England, and Nova Scotia. The most serious damage seems to be done in the eastern part of New York and in New England. The insect has no doubt been repeatedly transported to new localities in infested fruit, but it seems to have failed to establish itself, at least as a serious pest, south of the so-called Transition Life Zone.

Among the different varieties of apple there are extreme differences in susceptibility to the attack of the maggot. The varieties most severely injured are found chiefly among the summer and fall varieties, especially among those having a sweet or mildly acid flesh. No variety seems to be absolutely immune, and under certain circumstances many exceptions are found to the usual degree of susceptibility.

The winter is passed in the ground in the pupal condition. The flies leave the ground in the summer, beginning in southern Connecticut from the middle of June to early in July. Emergence continues for five weeks or more, and under Connecticut conditions is usually almost completed by the early part of August. Flies developing from maggots which breed in early fruit emerge a week or more in advance of those from later fruit. Early fruit is first attacked, partly because it is attractive to the flies earlier in the season, and partly because the flies from material underneath the trees bearing such fruit emerge earlier than those emerging from later fruit.

When the flies leave the ground the eggs in their ovaries are in an undeveloped condition, and a week or more elapses before any eggs are ready for deposition. The eggs are inserted into the apples just underneath the skin, and hatch in from 2 to 9 days; ordinarily in 4 or 5. The maggots hatching from the eggs tunnel through the apple, break down the pulp, and leave brown trails behind them. The larval period ranges from a minimum of about two weeks in drops of early maturing varieties to several months in hard winter apples. A high mortality occurs in the larval stages; in hard winter fruit which remains on the tree until harvest the mortality often reaches 100 per cent. Very few maggots are able to mature before the fruit has fallen and has had time to become mellow. When full-grown the maggots leave the apple, go a short distance into the ground, and enter the resting, or pupa, stage, inclosed within the dried and hardened larval skin.

In southern localities a few flies may emerge in the season in which the eggs are laid, but this occurs so late that few of such flies are able to find fruit suitable for oviposition, and still fewer of the maggots hatching from any eggs which may be laid by them are able to reach maturity. The greater part of the flies emerge in the following summer, but a few remain in the ground as pupae until the second summer, when they appear at the normal emergence period.

Record has been made of several predacious enemies, which are probably for the most part incidental and occasional, one egg parasite, and two larval parasites. On the whole, parasites and predators seem to exercise only an unimportant degree of control over the insect.

In the experiments with insecticides carried on in Connecticut, two applications of commercial powdered arsenate of lead, applied as for the codling moth, 1 to 1½ pounds in 50 gallons of water, have given satisfactory control of the apple maggot. Paste lead arsenate is probably equally effective, and a lime-and-casein spreader may be added if desired.

In southern Connecticut in average seasons the first application should be made about June 25 for early apples, and in the very first days of July for fall or winter fruit. A second application should be made two to three weeks after the first. In order to avoid excessive spray residue at harvest, emphasis should be placed on the first application, and later applications, if needed, should be rather light. If in spite of this precaution excessive residue is apparent at picking time, the fruit should be carefully cleaned before being placed on the market.

Poor control will result if untreated infestations are closely adjacent to the fruit that is sprayed. Especially at the time of the first application, all trees of all varieties should be sprayed, whether susceptible or not, and whether bearing a crop or not, although fair results are sometimes obtained by spraying only the susceptible varieties.

Where it is possible to do so without too great expense, the prompt removal of dropped infested fruit will prove a valuable auxiliary to spraying for the control of the apple maggot. To insure removal before the maggots have begun to leave the fruit, early summer fruit should be gathered twice a week, late summer and fall fruit once a week, and winter apples once in two weeks. The gathered fruit may be disposed of in any feasible way, so long as no maggots are allowed to complete their development and emerge as flies where they may have access to apple trees. The removal of the drops has no effect on the infestation of the current season, and for the immediate control of the apple maggot the grower should rely chiefly on spraying.

The experimental evidence shows that the other methods which have been tested are of little or no practical value in controlling the apple maggot.

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